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### Socioeconomic Analyses of Renewable Energy Options for Sub-Saharan Africa : A Regional and National Approach

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SOCIOECONOMIC ANALYSES OF RENEWABLE ENERGY OPTIONS FOR SUB-  
SAHARAN AFRICA: A REGIONAL AND NATIONAL APPROACH

A DISSERTATION

Submitted to the Faculty of  
Montclair State University in partial fulfillment  
of the requirements  
for the degree of Doctor of Philosophy  
in Environmental Science and Management

by

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Upper Montclair, NJ

May 2020

Dissertation chair: Dr. Pankaj Lal

MONTCLAIR STATE UNIVERSITY

THE GRADUATE SCHOOL

DISSERTATION APPROVAL

We hereby approve the Dissertation

SOCIOECONOMIC ANALYSES OF RENEWABLE ENERGY OPTIONS FOR SUB-

SAHARAN AFRICA: A REGIONAL AND NATIONAL APPROACH

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**Abstract**  
**SOCIOECONOMIC ANALYSES OF RENEWABLE ENERGY OPTIONS FOR SUB-  
SAHARAN AFRICA: A REGIONAL AND NATIONAL APPROACH**

by Sydney Oluoch

The energy demands of future Sub Saharan African (SSA) economies will be primarily driven by population and economic development. The expected primary challenge will be meeting the increased energy demands while mitigating greenhouse gas (GHG) emissions. This can be achieved by reducing dependence on fossil fuels and transitioning towards renewable sources of energy. This dissertation aims at assessing renewable energy options for SSA through three primary objectives. First, we provided insight into the scope, trends, and focus of renewable energy research in SSA by quantitatively reviewing scientific articles. The approach allowed us to determine the geographical scope, different types of renewable energy, distribution of articles in journals, and year of publication. The quantitative review can help inform renewable energy laws and policy and highlight areas for future research.

Second, we examined the relationship between renewable energy consumption with various economic, social, and environmental determinants using panel-data based econometric model developed for 44 SSA countries spanning over 1990 to 2014. The results helped identify factors that impact renewable energy consumption in SSA. This was through showcasing the need for SSA countries to invest in renewables to increase energy access, stimulate economies and to tap into the benefits of carbon markets. In view of the wide distribution of renewable energy potential in SSA, the chapter unveiled the need for policies that provide economic incentives and subsidies that are geared towards making renewable energy cost more competitive to traditional fossil fuels. Third, we conducted a comparative assessment of two case studies of SSA (Kenya and Rwanda), in-order to assess public awareness, acceptance, and attitudes

towards renewable energy. This objective addressed the need to integrate public input in the development of renewable energy policy. From our results it was apparent that the public in both countries, had a high level of awareness, acceptance and attitudes towards renewable, hence policy should shift to increasing knowledge and public participation.

In our last chapter, we evaluated public preferences towards attributes of renewable energy (biomass, solar, small-hydro, wind and geothermal) in Kenya and Rwanda using a discrete choice experiment approach. The objective addressed the need to assess tradeoffs between different attributes of renewable energy, in order to understand social, environmental and economic benefits and costs of non –market goods. Our findings highlighted differences in preferences between rural and urban residents of both countries. The general trends indicated a preference for solar, hydropower, wind, geothermal and biomass respectively. The public also placed a high utility on environmental impact, job creation and type of renewable energy.

Overall, this thesis investigates future renewable energy options for SSA, by using various econometric approaches to probe into the various issues that impact renewable energy development. In summary, there is overwhelming evidence of public support for renewables in our case-studies. The next step would be extending the case-studies to other SSA countries, and tasking decision makers to integrate public input in formulation and implementation of effective policies in-order to realize green and prosperous economies for SSA.

**KEYWORDS:** Renewable energy, Panel Data, Choice experiment, Rwanda, Conditional Logit, Random parameter logit, Sub-Saharan Africa

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To my family



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## **List of Abbreviations**

CESAC: Clean Energy and Sustainability Analytic Center

CGE: Computable General Equilibrium

IRENA: International Renewable Energy Agency

FiT: Feed in Tariff

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GMM: Generalized Method Moment

HH: Households

Ksh: Kenya Shillings

LPG: Liquefied Petroleum Gas

MW: Megawatt

MNL: Multinomial Logit

NISR: National Institute of Rwandan Statistics

NIMBY: Not in My Backyard

PV: Photo-voltaic

RPL: Random Parameter Logit

Rwf: Rwandan Francs

2SLS: 2 Stage Least Square

SDG: Sustainable Development Goal

SME: Small and Medium Scale Enterprise

SSA: Sub Saharan Africa

US: United States

WTP: Willingness to Pay

## SOCIOECONOMIC ANALYSES OF RENEWABLE ENERGY OPTIONS FOR SUB-SAHARAN AFRICA: A REGIONAL AND NATIONAL APPROACH

### 1. General Introduction

#### 1.1 Background

Energy related issues influence technical, societal, economic, and environmental aspects of everyday life (Dewaters and Powers, 2011). The increase in energy demand has raised concerns about rising carbon levels, which has triggered the utilitarian concept of green technology (Alam *et al.*, 2016; Dewaters and Powers, 2011). Both developed and developing nations agree that there is a need to shift from traditional carbon-based energy technologies to more environmentally friendly technologies (Inglesi-Lotz, 2016).

SSA has emerged as the one of regions with an increased economic growth with an estimated Gross Domestic Product (GDP) growth of 5.4% over the period of 2000 to 2010, adding \$78 billion annually to GDP (WEF, 2016; UNIDO, 2016). This growth goes hand in hand with the use of energy, leading to the question of how these emerging economies will meet their constantly increasing energy needs. Despite the economic growth, populations with access to energy are relatively lower as compared to other regions, with a gradual increase from about 27% to 44 % between 1990 and 2017 (Nyiwul, 2016; WDI, 2019). Outside of South Africa, Ghana, Mauritius, Cabo Verde, Comoros, Cote d'Ivoire, Equatorial Guinea, Gabon, Nigeria, and Seychelles, the population with access to electricity in SSA remains below 50% (Mohammed *et al.*, 2013). Many SSA governments have acknowledged the disparities in energy access and have intensified their efforts in tackling the numerous regulatory and political barriers that are holding back investment in energy supply (IEA, 2014). To meet the energy needs of economic growth,



SSA must strike a balance between mitigating climate change and using scarce financial resources for clean energy venture (Wesseh and Lin, 2014)

Despite SSA's abundant renewable energy capabilities, nearly 60% of the population still lack electricity (APP, 2015). The low electricity access levels is attributed to poverty, unstable economies, lack of foreign investment, slow economic growth, deficient infrastructure, lack of capital, insufficient governance, poor energy planning, financial misappropriation, and lack of institutional capacity in some SSA countries (Kahsai *et al.*, 2012; Mohammed *et al.*, 2013). Renewable energy consumption complements socio-economic parameters of development such as appropriate resource management, infrastructure and service development, administrative capacities and social welfare that ensure access to electricity (Inglesi-Lotz, 2016; Mohammed *et al.*, 2013). Despite, the capabilities of renewable energy to meet the challenges of energy provision, the effects of renewable energy on economic, social and environmental welfare of countries have not been adequately studied (Inglesi-Lotz, 2016; Salim and Rafiq, 2012). Drivers behind different types of non-renewable energy consumption have been well studied, whereas the drivers behind renewable energy remain unknown (Inglesi-Lotz, 2016; Salim and Rafiq, 2012). Therefore, this study emphasizes the importance of renewable energy consumption indicators for investigating energy planning and future policy needs. The main goal is to contribute to existing research by applying an econometric framework to assess the various social, environmental, and economic variables that influence renewable energy consumption in 44 African countries over a 25-year period. Using renewable energy consumption as the dependent variable, we include determinants that are rarely used, such as the corruption perception index, deforestation and human development index.

The economic literature on renewable energy is expanding, with many non-market valuation studies applied to understand the value of renewable energy from both an environmental and social welfare perspective (O’Keefe, 2014). With many emerging SSA economies expressing interest in adopting cleaner energy alternatives to counter fossil fuel consumption, it is critical to assess public opinion on issues relating to renewable energy development.

Literature on renewable energy development in SSA tends to focus mostly on the technological and power supply aspects of renewable energy, with few studies that investigate the social and environmental effect of renewable investments (Abdulahi et al., 2010; Mohammed et al., 2013). Hence, SSA countries require public input to guide development of appropriate renewable energy technologies. It is worth noting that there are few studies involving non-market value assessments. To meet the goals of access to clean and affordable energy, it is critical to conduct econometric analyses that help in gathering information on awareness, acceptance, attitudes, and preferences to these technologies. Given that SSA has a total of 48 countries, it would be infeasible to study all the countries. Consequently, we adopted a representative case study approach. The main criteria for selecting the case studies are existing renewable energy portfolios, development of renewable energy policy and representativeness of other SSA countries. Based on these guidelines, we selected Kenya and Rwanda due to their renewed commitment to diversify their energy portfolio, increase investments in renewable energy, and develop an energy policy over the last decade, resulting in significant strides in renewable energy development (APP, 2015). These two countries offer an excellent model for SSA, as they represent a total of 32 SSA countries in terms of size, economy, and population.

## **1.2 Research objectives.**

The overarching goal of this dissertation is to assess renewable energy options for SSA, first by analyzing renewable energy literature content in SSA to elucidate critical factors that determine renewable energy consumption. Quantifying the factors that influence renewable energy consumption in the context of Sub-Saharan nations. Followed by an assessment of public view on awareness, acceptance, attitudes, and preferences towards renewable energy, with the goal of improving policy. This research addresses three closely linked objectives and will focus on answering the following questions:

In Chapter 2, we assess renewable energy system development in SSA by quantitatively reviewing scientific publications to establish the current state of science on renewable energy in SSA. We posit that quantitative reviews will help develop recommendations and guidance for future research by identifying gaps and emerging areas of interest in the field of renewable energy studies in the region. We use VOSviewer, a software used to construct and view bibliometric maps (Van Eck and Waltman, 2009). Specifically, we investigate renewable energy research trends for the past 20 years, based on geographic distribution of studies, methods used in the corpus, categorization of renewable energy types (Biomass, Hydro-electric energy, Wind energy, Solar, and Geothermal energy), and common themes of renewable energy topics in SSA.

In Chapter 3, we examine the relationship between renewable energy consumption with various and environmental determinants, using SSA countries as a case study. We use a panel-data model of 44 SSA countries with annual data over the period of 1990 to 2014 to understand how renewable energy consumption impacts their economic, social, and environmental wellbeing. We have a specification and a scenario analysis to test the robustness of our model, as shown below:

- a) In specification 1, we look at the relationship between Renewable energy consumption and social, economic, and environmental variables for 44 SSA countries.
- b) In the scenario analysis, we include corruption perception index (a governance performance indicator) for 23 selected SSA countries.

In Chapter 4, we determine the level of awareness, acceptance, and attitudes towards renewable energies (solar, biomass, wind, small-hydro and geothermal) in Kenya and Rwanda as a comparative case study. By using a national survey that employs a random stratified approach, we assess the level of awareness, acceptance, and attitudes towards different renewable energy types (solar, biomass, wind, small-hydro and geothermal). Specifically, we used ordered logit regression to estimate the correlation between awareness and attitudes of the population towards renewable energy.

In Chapter 5 and 6, we determine attributes that affect individual's willingness to pay for renewable energy development for Kenya and Rwanda. Specifically, we estimate the value of positive and negative externalities of potential renewable energy projects with the goal of understanding the socio-economic and environmental aspects that influence public preferences for renewable energy development. The renewable energy technologies considered in this study include geothermal, wind, solar, hydropower (small-hydro), and biomass (biofuels and biogas). We look at the trade-offs that the public in both rural and urban settings consider in their preferences. We investigate the socio-demographic and household characteristics such as gender, income, and age of the public in Kenya and Rwanda that may play a role in influencing their preferences to renewable energy development.

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## 2. Quantitative review of renewable energy studies in SSA<sup>1</sup>

### 2.1 Introduction

Climate change remains one of the greatest challenges facing the world, especially in developing countries that are also the least contributors to climate change (Omisore, 2018). Climate change is characterized by increases in global temperatures and sea level rise that may trigger events such as floods, droughts, and heat waves (Omisore, 2018). This has led to rapid consensus among nations worldwide to shift from traditional carbon-based energy technologies to more environmentally friendly technologies (Inglesi-Lotz, 2016). Sub-Saharan African (SSA) countries will be the most vulnerable to the catastrophic consequences of climate change such as heightened threat of food security, increasing scarcity of water resources, deterioration of natural resource's productivity, shrinking biodiversity, decline in human health, land degradation, and desertification (Inglesi-Lotz, 2016; Omisore, 2018). Most SSA countries have yet to come to terms with the reality of climate change and its consequences. Although developed countries have pledged to provide US \$ 100 billion in support by 2020, SSA countries still need to make greater efforts to increase institutional commitment to avoid the effects of climate change (Omisore, 2018). Renewable energy technologies have the capacity to bridge the development gap in the region where there are abundant untapped renewable energy resources (Mohammed et al., 2013). The advantage that SSA countries have over developed countries is that they can leapfrog directly and adopt innovative technologies instead of going through the learning curve of energy systems that have resulted in great environmental impacts (Mohammed et al., 2013).

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<sup>1</sup> A modified version of this chapter has been published in the Journal of Energy and Natural Resources. Oluoch et al. *A Snapshot of Renewable Energy Research in Sub-Saharan Africa*. Vol. 8, No. 4, 2019, pp. 146-154. Doi: 10.11648/j.jenr.20190804. 2

Global investments in renewable energy projects in 2015 rose 5% to US \$285.9 billion (GTREI, 2016). In the same year, investments in renewables in developing countries outweighed those in developed economies with a total investment of US \$156 billion, with China, India and Brazil leading the group. In the Middle East and Africa, renewable energy investments increased by 58% to US \$2.5 billion, with most of the investments originating from South Africa and Morocco. South Africa has made remarkable progress in recent years by investing as much as US \$4.5 billion in clean energy initiatives (GTREI, 2016). However, there is a significant global disparity in renewables investment, with only one out of 48 countries in Sub-Saharan Africa (SSA) making significant strides (GTREI, 2016).

The reasons for the disparities in renewable energy investments include poverty, unstable economies, lack of foreign investment, slow economic growth, deficient infrastructure, lack of access to capital, insufficient governance, poor energy planning, financial misappropriation, and lack of institutional capacity in some SSA countries (APP, 2015; Kahsai et al., 2012; Mohammed et al., 2013). What is concerning is the fact that the renewable energy sector in SSA is primarily dominated by traditional biomass such as charcoal and fuelwood harvest, which have significant environmental implications. Excessive use of traditional biomass resources can be attributed to low levels of education and lack of economic empowerment among the rural population to pursue greener alternative forms of energy (Mohammed et al., 2013). The slow rate of technology spread, and application further hinders progress in the field of renewable energy (Kahsai et al., 2012). Dependence on woodfuel has led to environmental degradation in the region, and strict policy measures by governments are needed to increase access to modern renewable energy services (Mohammed et al., 2013). The diverse nature of renewable policies pursued by SSA countries also poses a challenge for regional integration of renewable energy



approaches that could benefit the countries through cooperative mechanisms such as sharing of resources, information, technology, and ideas (APP, 2015; Kahsai et al., 2012; Mohammed et al., 2013).

There remains a large population in SSA without access to electricity. Securing electricity access for SSA through renewable sources could help address the twin problems of affordability and environmental degradation. Studies in SSA highlighting wide disparities in electricity access and the underlying factors that cause them have been conducted (Diechmann et al., 2011; Eberhard and Shkaratan, 2012; Mohammed et al., 2013). Hancock (2015) observed that although there are many journals that focus on environmental and energy issues in SSA, the region is still the least represented among the world's major energy-focused journals. In addition, most journals covering energy topics in SSA focus on narrow areas, such as cookstove or general topics on sustainable energy (Hancock, 2015). In this context, we focus on using quantitative reviews to study various trends in renewable energy research in the region. Due to the lack of a quantitative assessment of trends in renewable energy research in SSA, we seek to bridge this research gap.

This chapter quantitatively reviewed scientific publications in order to establish the current state of science on renewable energy in SSA. We use VOSviewer, which provides quantitative reviews by constructing and viewing bibliometric maps (Van Eck and Waltman, 2009). VOSviewer facilitates the construction and clustering of term maps by displaying important terms in the titles, keywords, and abstracts of the publication, thereby providing a visual representation (Van Eck and Waltman, 2009; Zeraatkar, 2017). Extraction of the most frequently used keywords to identify the main topics in renewable energy research and provide insights as to current geographic and sectoral hotspots in renewable energy research.

Quantitative review is a research technique that provides a comprehensive picture of a specific subject area by mapping scientific publications. The technique facilitates an objective categorization of works and items in numerical terms (Kayser and Shala, 2014). Quantitative review broadly includes text mining, systematic reviews, longitudinal reviews, and bibliometric mapping. Text mining is the process of deriving information from text by devising patterns and trends (Cookey et al., 2017; Kayser and Shala, 2014). Unlike text-mining that uses the whole article, for bibliometric mapping information retrieval is based on the title, keywords, and abstract (Liew et al., 2014).

Quantitative reviews have been used extensively by researchers in the field of environmental management, in studies involving ecosystem services (Luederitz et al., 2015) and sustainability (Rivera et al., 2014; Woon et al., 2014). In the domain of renewable energy, a study by Puzzolo et al. 2016 used systematic reviews to investigate the barriers and enablers of adoption and sustained use of clean fuels in resource-poor settings. They focused on household fuels such as LPG (Liquefied Petroleum Gas), biogas, solar cooking, and alcohol fuels in middle-income countries in Africa, Latin America, and Asia. Rizzi et al., 2014 argued for the need for a study such as ours by stating that despite the need to incorporate quantitative review techniques in the field of renewable energy research to analyze scientific knowledge production, its applications were rare.

## **2.2 Methodology**

The literature search encompassed publications from the Science Direct database, which is a subscription based, professionally curated collection of publications base provided by Elsevier (Table 2.1). We chose Science Direct because other search engines such as Google Scholar include extraneous publications, while databases such as SpringerLink, Web of Science,

and Scopus had lower numbers of publications of interest, many of which overlapped with Science Direct. We included a wide range of publications, defined as original research, commentaries, symposiums, reviews, case reports, and short communications in order to conduct a comprehensive review of publications in this field. The corpus included publications written in English in the period of 1990-2016. We refined the search to capture publications in renewable energy by using the term, ‘renewable energy’ and ‘SSA’. After applying the exclusivity criterion criteria, our final analysis corpus consisted of 373 sources, which was lower than the original 1954 retrieved publications, accounting for 19.1% of the corpus.

**Table 2.1:** Table indicating various databases and search query results for Africa and other continents.

Search term	Data base				
	Scopus	Springer Link	Web of Science	Google Scholar	Sci-Direct
Renewable energy in					
Sub Saharan Africa (SSA)	198	1751	81	58,700	<b>1,954</b>
Europe	3,574	21,394	1,093	617,000	34,505
Middle East	350	8,202	108	113,000	9850
Asia	1050	11,386	228	211,000	13,839
South America	265	8,550	61	204,000	9,806
North America	870	9,903	99	103,000	12,500
Australia	996	11,771	353	287,000	18,623

\*The table above gives a brief overview of the state of research of renewable energy for SSA in comparison to other regions of the world based on the term “renewable energy in the affiliated region” in various search engines and databases.

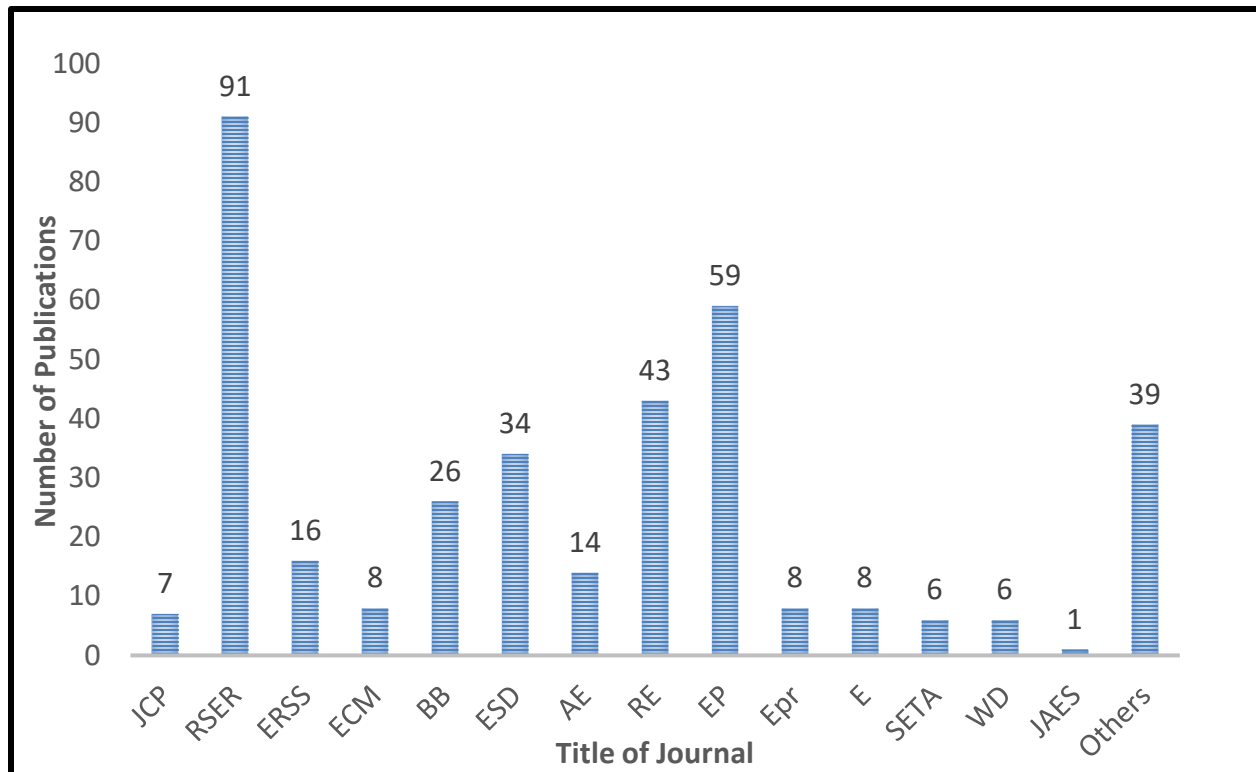
The 373 selected publications were categorized based on the geographical distribution, publication dates, methods used, renewable energy by type (wind, solar, biomass, hydroelectricity, and geothermal), and name of journal. The criteria for reporting the geographic distribution of renewable energy research are based on the countries concerned by the research.

For geographic distribution of publications in the corpus, we color-coded the countries using the software Tableau 10.0. For Bibliometric mapping, the portable document format (pdf) files were downloaded and converted into text files and analyzed using VOSviewer 1.5.4. Using this technique, we identified a list of ‘words’ commonly encountered in renewable energy research in SSA over the past 26 years. We used network visualization and density visualization to illustrate the specific word patterns that appear most frequently in the literature.

## **2.3 Results and Discussion**

### **2.3.1 Distribution of publications on Renewable Energy in SSA**

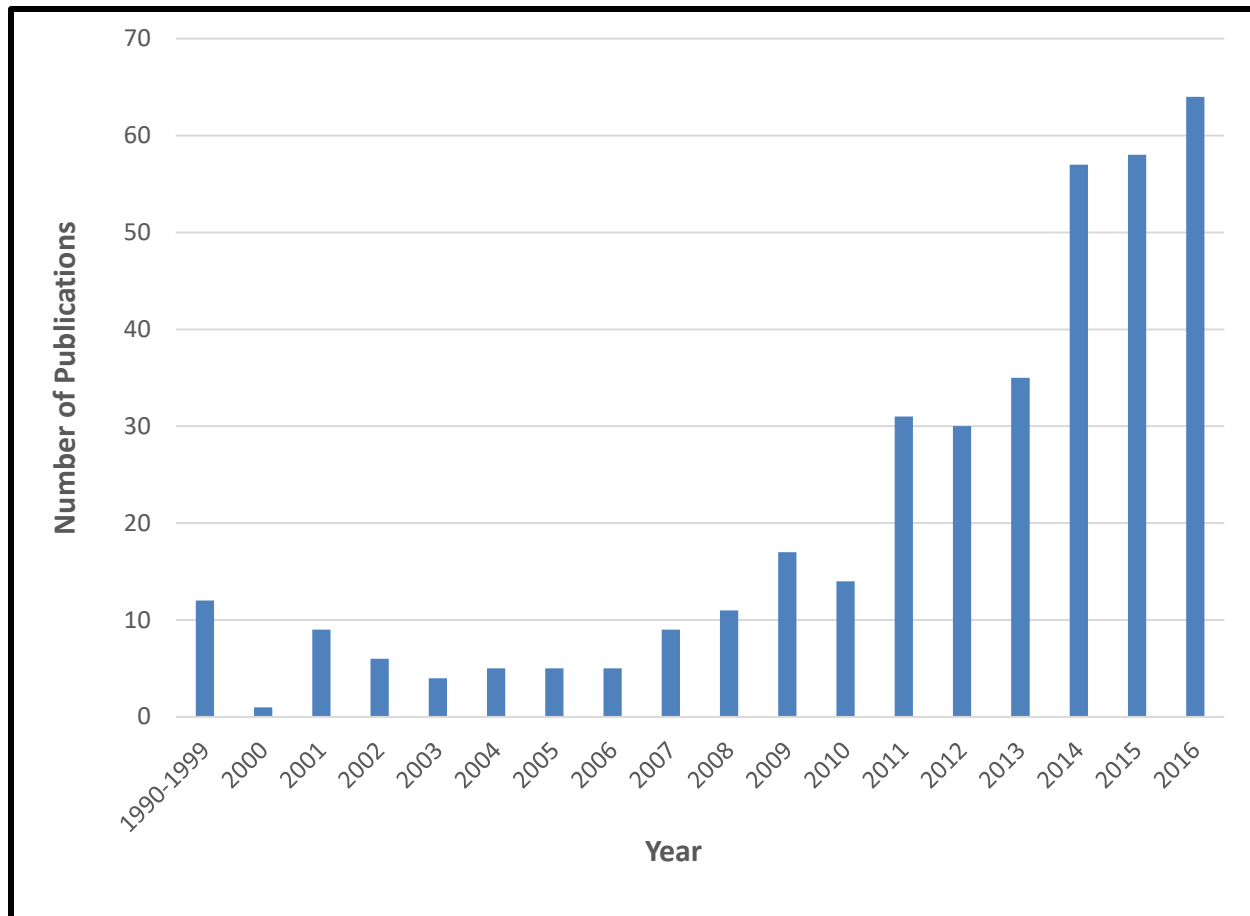
The 373 research publications were distributed across 44 different journals. The Renewable and Sustainable Energy Reviews journal had the largest share of publications at 24.86%, followed by Energy Policy at 16.12% and Renewable Energy at 11.75% (Figure 2.1). Other journals that had less than 3 publications were placed in the ‘others’ category that comprised of a grouping of 29 journals.



**Figure 2.1:** Number of peer reviewed publications distribution by journals type in SSA (1990 to 2016)

**Note:** **JCP** -Journal of Cleaner Production; **RSER** -Renewable and Sustainable Energy Reviews; **ERSS**-Energy Research and Social Science; **ECM**-Energy and Conservation Management; **BB**-Biomass and Bioenergy; **ESD**-Energy for Sustainable Development; **AE**-Applied Energy; **RE**-Renewable Energy; **EP**-Energy Policy; **Epr**-Energy Procedia; **E**-Energy; **SETA**-Sustainable Energy Technologies and Assessment; **WD**-World Development; **JAES**-Journal of African Earth Sciences.

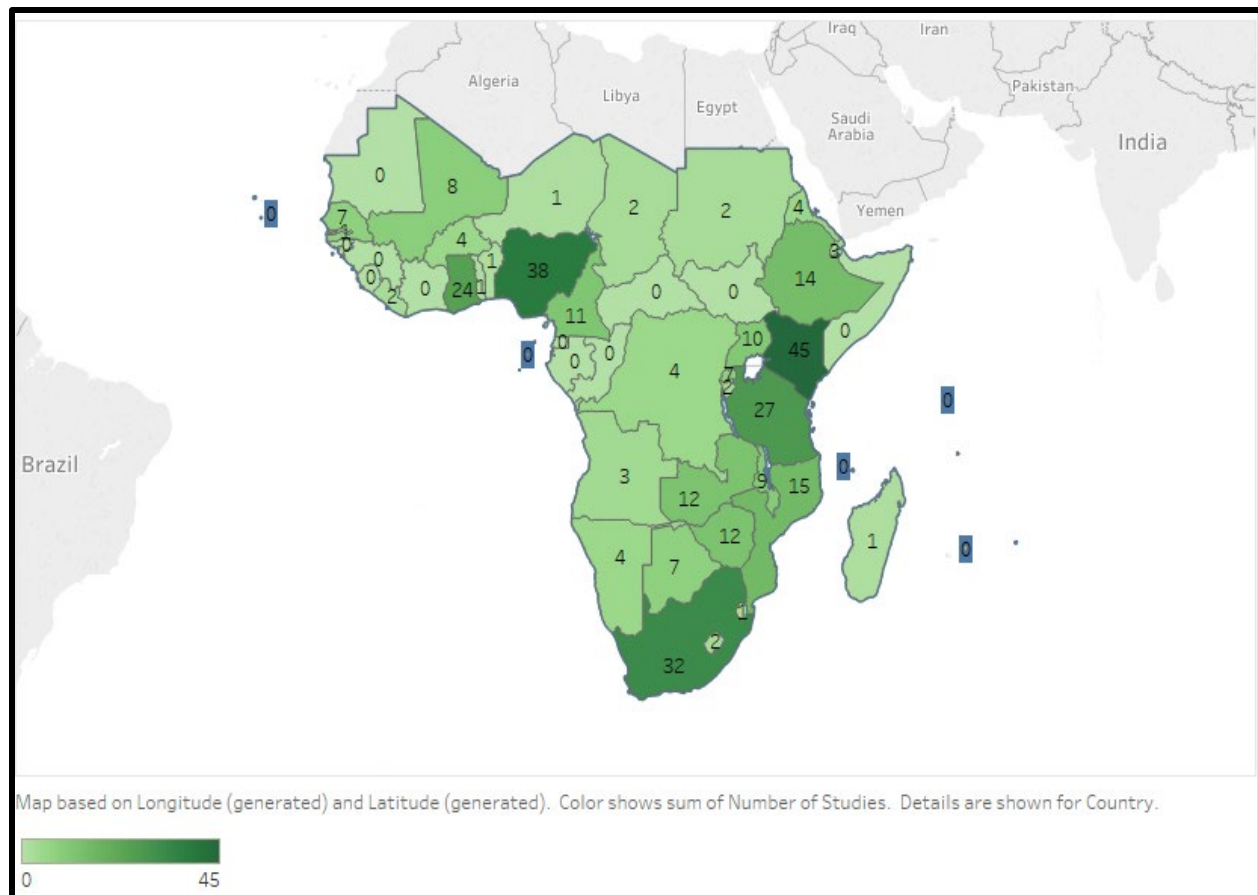
Of the 373 publications, 77.48% were published between 2010 and 2016, with 19.3% between 2000 and 2010 and only 3.28% between 1990 and 1999. The increase in number of publications between 2010 and 2016 could be attributed to increased focus on renewable energy in the region, as well as international agreements such as the Kyoto Protocol and its resulting discussions that prioritized renewable energy (Celiktaş et al., 2009). From 2010 to 2016, SSA publications experienced a peak delay, indicating a lag in catching up with global trends in renewable energy research (Figure 2.2).



**Figure 2.2:** Number of peer reviewed publications in SSA between 1990 to 2016.

### 2.3.2 Geographical Distribution of Renewable energy publications

Our results suggest that renewable energy research was spatially distributed across SSA with, few countries acting as research hotspots (Figure 2.3). A total of 316 publications researched specific countries within SSA, while the remaining 57 publications focused broadly on SSA, representing 15.28% of the total. Out of the 316 publications focusing on specific countries, 14.25% focused on Kenya, 12.02% focused on Nigeria, and 10.12% focused on South Africa, which is in sync with renewable energy policy discussions and implementation in these countries.



**Figure 2.3:** Illustrating geographical distribution using color coding that represents the frequency of peer reviewed publications focusing on renewable energy in SSA countries.

Overall, there are several publications related to renewable energy in SSA, but little attention is paid to many constituent countries. Our analysis suggests that countries such as Madagascar, Gabon, Democratic Republic of Congo, Chad, Niger, Central African Republic, Somalia, Benin, Cote-D'Ivoire, Togo, Rwanda, and Burundi were underrepresented in renewable energy publications, with the number of publications for each country ranging between 0 and 5 in the 26-year period. By focusing on the region, it was easy to gauge that these countries can benefit from additional renewable energy research.

### 2.3.3 Methods applied in corpus

The basis of characterization on the methods used in our study corpus of 373 research publications hinged on how the authors described their publications. Some publications used

more than one method; for example, there are studies that had some aspect of surveys and interviews, case analysis, or modeling. We identified and focused on the primary study methodology outlined in each of the 373 publications. This was to avoid overlap and double counting in terms of study methodologies employed. We used 8 categories to classify the publications, namely: reviews, econometrics, surveys and interviews, software and modeling, techno-economic analysis, socio-technical analysis, case studies and ‘other’ categories (Table 2.2).

**Table 2.2:** Description of methods used in the corpus.

Category	Methods used	Representation in corpus by percentage
Review	Literature review, critical review, longitudinal overview, quantitative review	24%
Econometric modeling	Contingent valuation, regression analysis, macroeconomic assessments, discrete choice, panel data	9%
Software and Modelling	Scenario analysis, satellite derived models, power system dispatch models, spreadsheet models, satellite base irradiance models, system level optimization models, business model, top-down models, spreadsheet models.	14%
Surveys and interviews	Surveys (open ended and closed ended), semi-structured interviews, qualitative studies.	13%
Case studies	Examination, investigation, evaluation, analysis and case study.	20%
Techno-economic analysis	Techno-economic analysis	10%
Socio-technical analysis	Socio-technical analysis	7%
Others	Lead articles, editorials, symposiums, viewpoints, short communications and technical notes	3%

The most used research method was reviews, which includes 91 studies, accounting for 24% of the total. This was closely followed by case studies, comprised of 74 studies, accounting for 20% of the total. A sizeable portion of publications comprised of 6 other types of methods applied in

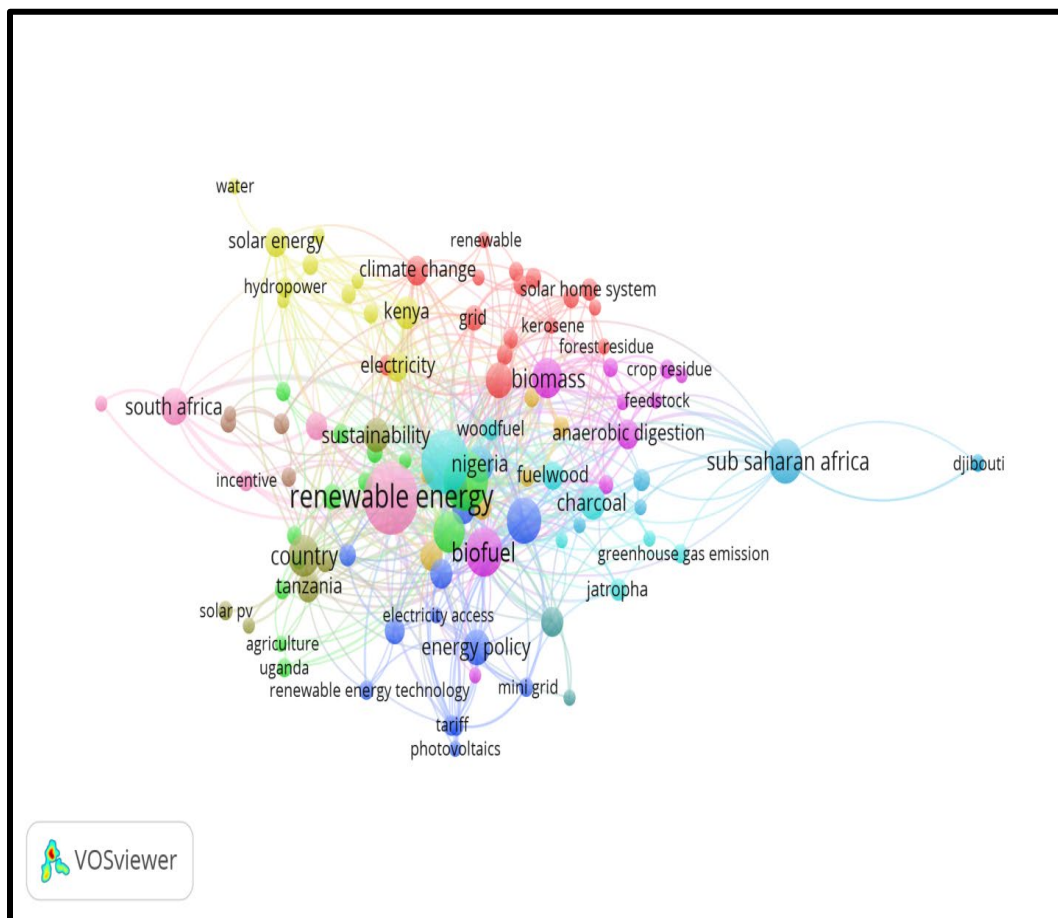


the corpus, including “software and modeling (52 publications, 14% of total), “surveys and interviews” (48 publications, 13% of total), “Techno-economic analysis” (38 publications, 10% of total), “Econometrics” (32 publications, 9% of total), “Socio-technical analysis (27 publications, 7% of total) and “Others” (11 publications, 3% of total). It is evident from our analysis that the need to increase renewable energy in SSA coupled with the global concern for climate change has led to an increase in scholarly literature focusing on technical and economic aspects of renewable energy (Hancock, 2015). Hancock (2015) observes that renewable energy literature with a social dimension are still lacking in the research literature within the region. This is in agreement with our findings, as most literature with a social dimension was covered under socio-technical analysis.

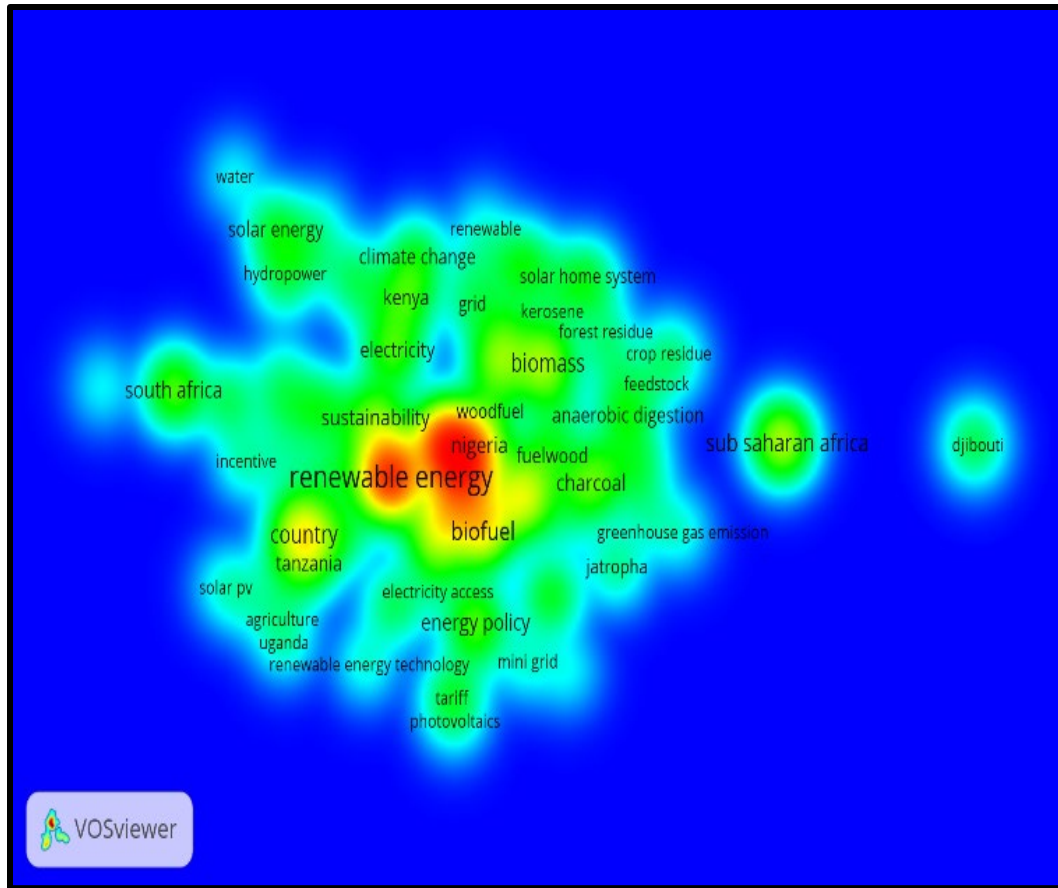
#### **2.3.4 Bibliometric Mapping: Network visualization and Density visualization**

Density visualization works by displaying the text size and distance between items thereby, denoting its contribution by using color heat maps to represent the density of items based on the number and importance of the neighboring items (Figure 2.4 and 2.5). It is a useful tool to get an overview of general structure by highlighting the most key areas of the map (Van Eck and Waltman, 2009). Overall, the terms were placed in six categories based on the topic of focus, bringing up five distinct categories (biomass, solar, wind energy, hydropower, and geothermal related terms) and one other category for other important terms. There are 8680 terms for renewable energy in the SSA corpus, of which 642 meet the threshold of at least 10 words that surround the renewable energy term. Biomass related terms formed 64.33% of the total renewable energy words in the abstract, the most common terms being ‘biomass’, ‘biofuel’, ‘charcoal’, ‘biogas’, ‘Jatropha’, ‘fuel-wood’, and ‘biodiesel’. Solar related words formed 5.05% of the total renewable energy words with the

most common terms being ‘solar home system’, ‘solar energy’, and ‘photovoltaics’. Wind related terms formed 3.51% of the total renewable energy words with the term ‘wind’ dominating the category. Hydropower related terms formed 4.54% of the total number of words with terms such as ‘hydro’ and ‘water’ featuring in the abstract. Other important terms in the abstract were ‘renewable energy’, ‘development’, ‘electricity access’, ‘energy policy’, ‘climate change’, ‘sustainability’, and ‘greenhouse gas emissions. Finally, countries that featured in the density visualization were Nigeria, Kenya, South Africa, and Uganda (Figure 1.4 and 1.5).



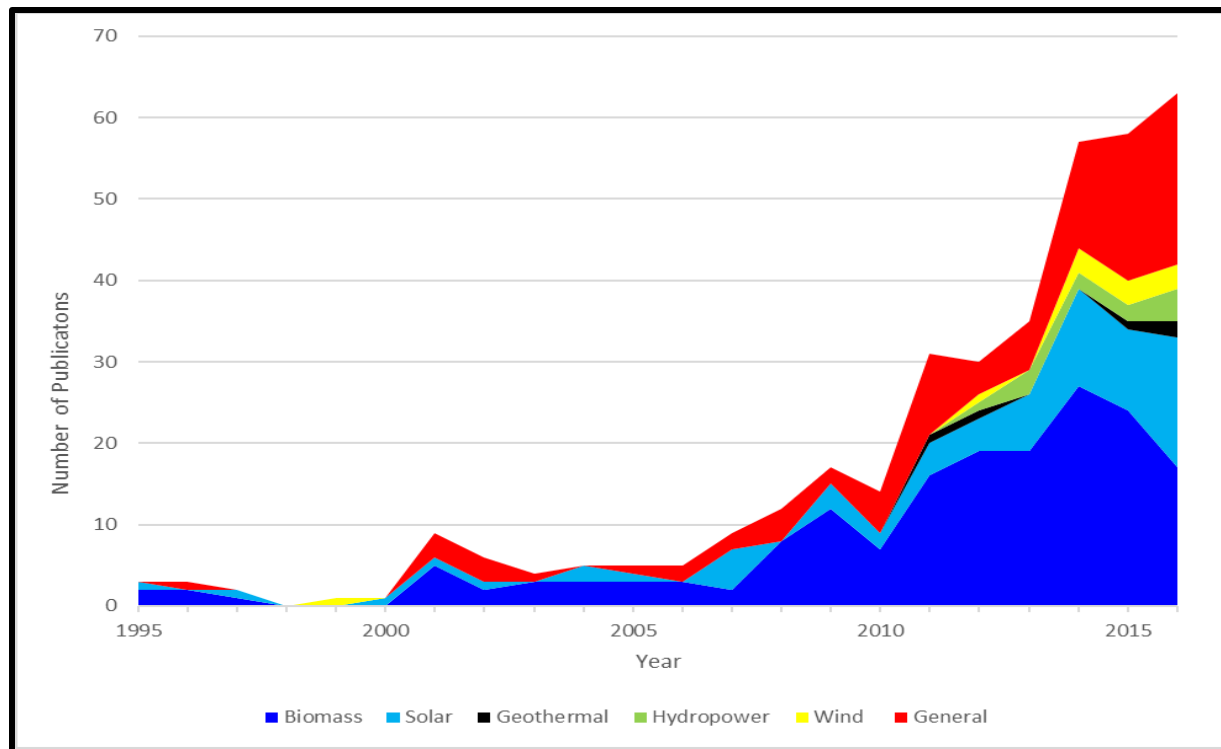
**Figure 2:4:** Network visualization of peer reviewed publications in SSA



**Figure 2.5:** Density visualization of peer reviewed publications in SSA

### 2.3.5 Distribution of publications about renewable energy by type.

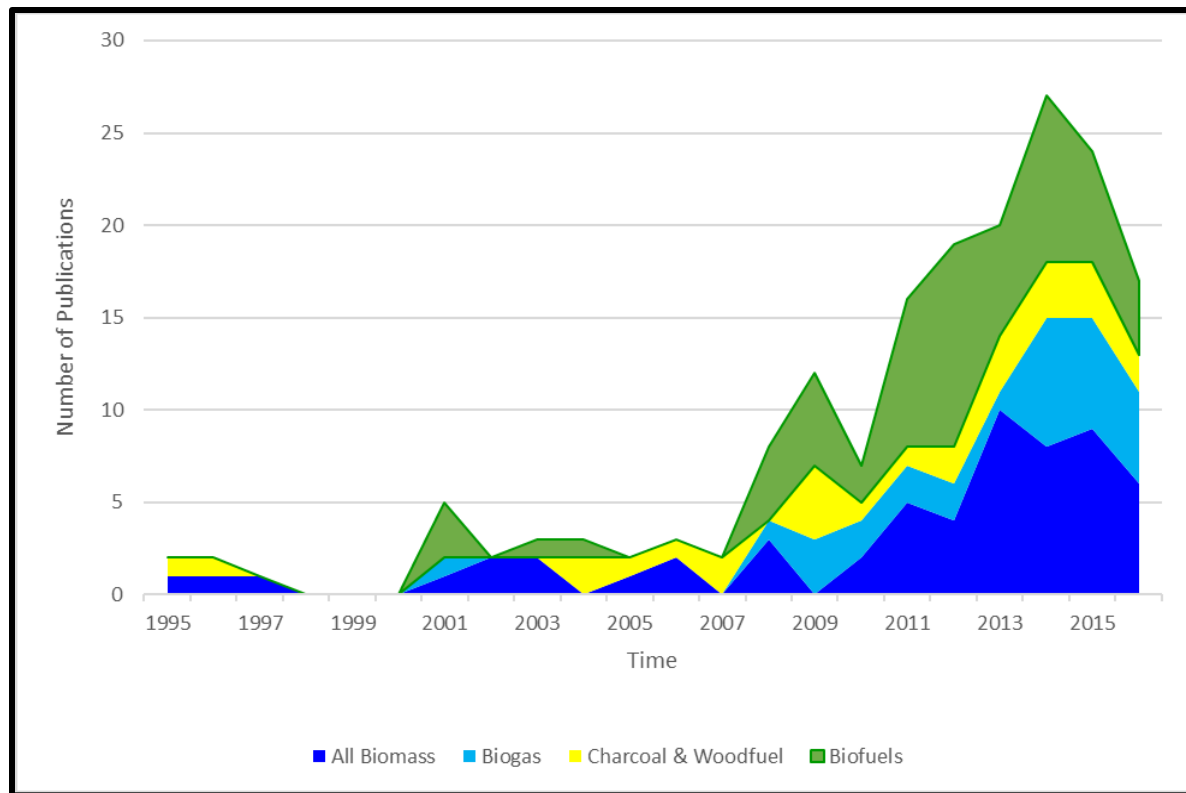
It is evident that before the year 2000, there were few publications, with less than 3 per year. Between 2000 and 2010, there was a steady increase in growth of number of publications in all domains, especially for biomass energy. There has been an increase in number of publications for all domains, particularly for biomass and solar with an average of 19 and 8 articles per year respectively from 2010 to 2016. Being the dominant source of renewable energy for the past half century in SSA, we expected that hydropower publications would have higher number of publications over the years (Collier and Venables, 2012). However, our analysis suggests that the renewable energy research in the region is mainly focused on biomass and solar (Figure 2.6).



**Figure 2.6:** Area chart for the number of publications by renewable energy type.

### 2.3.5.1 Biomass

A total of 175 publications (47% of total) focused on biomass from 1990 to 2016. Among these publications, 33% focused on biofuels, 16% focused on biogas (municipal solid wastes and animal residues), 20% focused on charcoal, wood fuel, briquettes, and wood chip residues, with the remaining 31% discussing all biomass sources together (Figure 2.7). There was an increased presence of biofuel and biogas publications in comparison with charcoal and wood fuel. This suggests increased research transition from the traditional sources of biomass to more efficient biomass options such as biodiesel plants, bioethanol production using crops, grasses, and other feedstocks, especially from 2008 onwards.



**Figure 2.7:** Area chart for distribution of biomass related publications in SSA from 1990 to 2016.

### (i) Biofuels

Biofuels encompass broadly available sources of biomass such as biodiesel, bioethanol, biogas, biomethanol, and biohydrogen (Jumbe and Mkondiwa, 2013). SSA's biofuel crops include cassava, jatropha, castor oil and palm oil fruits, which are grown mainly in Nigeria and Ghana (Jumbe and Mkondiwa, 2013). Other countries with major biofuel production potential include Malawi, Ethiopia, Sudan, Tanzania, Swaziland, Uganda, South Africa, Kenya, Niger, and Togo (Mohammed et al., 2013). Biofuel development in SSA is mainly driven by the need to mitigate the impact of high fuel prices and to enhance rural incomes (Jumbe and Mkondiwa, 2013). The choice of feedstock for biofuel is based on cost, availability, economic viability, and sustainable growth in SSA. Other suitable attributes are biodegradability, non-toxicity, and

emission levels (Onoji et al., 2015). In cases where biodiesel production stems from edible oil plants such as soybean, rapeseed, sunflower, safflower oil, palm oil, and canola, there is bound to be competition with food, pharmaceutical, and cosmetic uses, which results in high prices. Hence preference in SSA has been for use of non-edible oils from seeds of rubber, *Jatropha*, castor, linseed, *moringa oliefera*, cotton, and tobacco plants to avoid fuel-food crisis (Onoji et al., 2015).

The publications of *jatropha* increased significantly in the mid-2000s, accounting for 18% of the total publications in the biofuel category (11 publications). This event can be attributed to the then prevailing view of *Jatropha* being a crop that had the potential to tackle the challenges of providing energy, while providing suitable incomes due to its ability to prevail on marginal land (Jumbe and Mkondiwa, 2013). Most of these publications discussed the potential of successful application of *Jatropha* in small scale development projects for provision of energy to rural SSA and reduce dependence on fossil fuels (Almeida et al., 2014; Baldini et al., 2014). The net positive energy balance and the potential to reduce greenhouse gases indicate that this feedstock is an environmentally sustainable choice (Baldini et al., 2014; Basili and Fontini, 2012). However, the key challenges to successful deployment of *Jatropha* were land issues in terms of scale and the time required for the crop to mature (Arevalo et al., 2014; Eckart and Henshaw, 2012; Ehrensperger et al., 2015)

The key issue discussed in the publication surrounding the deployment of biofuel alternatives is the redistribution of farmland dedicated to food crops to these non-food energy crops. The lack of proper regulatory framework further put pressure on food security and the environment (Amigun et al., 2008; Arevalo et al., 2014; Baldini et al., 2014; Fulquet and Pelfini, 2015). Since most bioenergy policies in SSA have been formulated in the past decade, they often lack detailed strategies and appropriate institutional frameworks for implementation (Amigun et

al., 2008). In addition, some SSA governments are often interested in foreign direct investments that facilitate multinational companies access to land rather than protecting customary land rights or securing large-scale agricultural land (Fulquet and Pelfini, 2015). This can be attributed to weak links between the major stakeholders (local energy developers, non-governmental organizations, community leaders, researchers) and government that has left investment opportunities exposed to the self-interest of transnational companies, who tend to focus on the extraction of large volumes of resources for export and lack mechanisms to ensure benefit to local populations (Fulquet and Pelfini, 2015).

## **(ii) Charcoal and Woodfuel**

Twenty-seven studies (16% of publications in biomass domain) focused on charcoal and wood-fuel (Figure 2.7). Most of these publications focused on development of technologies to improve wood stove efficiency. The focus of these studies was on the opportunities, alternative methods of efficient charcoal production, formalization of value chains and livelihood outcomes, governance, policy interventions, changing perspectives, challenges, and way forward in the charcoal and wood-fuel industry. An example of this kind of study was one by Mohammed et al., 2013, who reviewed the challenges surrounding the consumption of woodfuel and charcoal in Nigeria, Uganda, and Ghana. The proposed solutions by the authors were to increase access to electricity, improve reliability and security of renewable energy options.

Given that indoor air pollution from wood smoke results in 600,000 premature deaths annually in SSA (Hancock et al., 2015), emphasis has been placed on improved practices in the use of traditional biomass in rural households. Some of the initiatives deployed include the UN Sustainable Energy for All (SE4All) and the Global Alliance for Clean Cook Stoves, which explore technologies that serve to reduce deforestation and indoor air pollution (Hancock et al.,

2015; Smith et al., 2015). The focus on initiatives to improve stoves to effectively use traditional biomass appears to be both donor and national government driven (Hancock, 2015; Smith et al., 2015). There seems to be growing realization that since most rural households depend on wood fuel which is readily available and cheap, improved stoves can be an environmentally and healthy way to harness the energy (Smith et al., 2015).

### **(iii) Biogas**

Biogas and bio-wastes comprise of 30 publications or 17% of the biomass domain (Figure 2.7). Rupf et al. 2016, evaluated the feasible technologies and feedstock for biogas production in SSA. They discussed a range of options such as livestock manure, feedstocks from households, bio-digesters that take up crop residues, and municipal solid wastes. They found that the key factors while designing a suitable biogas option included feedstock availability, water supply, energy demand, local materials, labor, and level of commitment to operate and maintain the bio-digesters (Rupf et al., 2016). Other research focused on the current status and future prospects of SSA biogas plants, policy impact, socio-economic challenges, capacity cost and location cost analysis caused by the widespread adoption of biogas digesters (Mohammed et al., 2013; Mwirigi et al., 2014; Rupf et al., 2016).

Biogas as a potential renewable energy source has become appealing to developing country governments, as it boosts renewable energy output while easing carbon emissions from fossil fuels (Mwirigi et al., 2014) Biogas digesters have been installed in Burundi, Botswana, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, Zimbabwe, South Africa, Kenya, Tanzania, and Uganda (Smith et al., 2015; Mwirigi et al., 2014). The main goal of most publications on biogas is to understand the potential factors that



hinder the development of biogas. Despite the feasibility, sustainability and effectiveness of multiple pilot projects, there is no large-scale biogas plants (Mwirigi et al., 2014).

### **2.3.5.2 Solar energy**

Seventy-one publications in the corpus focused on solar energy, constituting 19% of the publications and making it second largest group of studies related to renewable energy (Figure 2.6). Solar energy publications seem to follow a similar trend to biomass energy studies, with a few publications before the year 2000 followed by a steady increase between 2000 and 2010 and a marked increase from 2010 to 2016.

Most of the publications related to solar energy in SSA focused on off-grid solar solutions that provide lighting for rural communities (Aissa et al., 2014). The publications focused on the key issues surrounding off-grid solar technology such as falling system costs, cost-effectiveness, comparative costs with other regions of the world, affordability, financing options, environmental impact, effective policy framework for adoption of technology, and poverty alleviation (Baurzhan and Jenkins, 2016; Karekezi and Kithyoma, 2002; Lemaire, 2011; Mandelli et al., 2016; Opiyo, 2016). One of the major technical limitations in the provision of solar technology has been the ability to store the solar energy from the panels in a battery (Lemaire, 2011). The high costs associated with unit installation make it a prohibitive investment for the rural communities, but some communities have come up with innovative small-medium entrepreneurial solutions that provide credit facilities for installation of panels and batteries (Lemaire, 2011; Mandelli et al., 2016). Publications have also investigated the techno-economic ability of solar panels, especially in projects that applied cheap solar energy to pump water, drive mills, power refrigeration, and heat water. Some studies investigated the efficacy of solar power units for small-scale businesses such as phone charging and copier and faxing services in remote

areas, which alleviated the need for consumers to travel longer distances (Banks et al., 2009). Grid-connected, solar photo-voltaic (PV) studies have been relatively few in the SSA as compared to off-grid solar PV solutions. An example was a publication based on prospects of grid-connected solar PV in Kenya, which used a systems approach to evaluate the potential of grid connected solar PV in combination with existing hydropower reservoir to displace diesel generation (Akinyele et al., 2015; Rose et al., 2016).

### **2.3.5.3 Other forms of renewable energy (Wind, Hydropower and Geothermal)**

A total of 14 publications focused on wind energy between 1990 and 2016, constituting 4 % of the total number of publications in the corpus (Figure 2.6). Mukasa et al. 2015 provided a comprehensive overview of the region's wind energy sector, exploring the evolution of wind energy markets and structural characteristics affecting development of wind energy projects. From an economic perspective, they found that most of these projects are shifting from concessional funding to private sector funded projects, with the public sector performing a significant role in wind energy (Mukasa et al., 2015). Many other publications have evaluated the wind energy potential of in various regions of SSA. It is noteworthy that all sources of wind energy publications were based onshore wind technology.

Hydroelectric related topics formed 4% of the corpus, with a total of 13 publications between 1990 and 2016 (Figure 2.6). Hydroelectric sources have been a dominant source of renewable energy for decades in the region (Collier and Venables, 2012), but the number of publications were few. A decline of hydropower in SSA in recent decades is due to changing climatic conditions from global warming that has shifted the seasonal patterns (Collier and Venables, 2012) Demissie and Solomon (2016) and Cole et al., 2014, used climate modeling approaches to investigate how extreme variation in rainfall increased the vulnerability on

hydropower systems. Based on their model, Demissie and Solomon (2016) determined that the hydropower system lacks resilience to the effects of climate change. However, Cole et al., 2014 found that planned investments are at minimal risk in terms of not generating returns. The finding of the later study seems to contradict the expected adverse effects of climate change on hydropower.

About 1% of the publications covered the domain of geothermal energy, with only five studies discussing the topic (Figure 2.6). Due to geographical features, geothermal energy is mainly exploited in Ethiopia and Kenya because of the geological characteristics of the Great Rift Valley that passes through the two countries. In general, there has been a paucity of publications, especially in Ethiopia and Kenya, which have considerable geothermal potential.

## **2.4 Conclusion**

We examined emerging trends in renewable energy research in peer-reviewed publications with the goal of identifying research gaps, research perspectives, current knowledge, and the trajectory of research over time. We illustrated that the topic of renewable energy has attracted a growing number of research perspectives in SSA. From the corpus of 373 publications, the Journal of Renewable and Sustainable Energy Reviews formed the largest share with 24.8%, followed by Energy Policy at 16.1%, and Renewable Energy at 11.7%. The temporal analysis confirmed that the scientific publications in the renewable energy field experienced a substantial growth during the period between 1990 and 2016, with biomass energy publications being the most dominant renewable energy type studied in SSA.

The geographical distribution of renewable energy publications can play a vital role by pointing out spatial gaps and overlaps, highlight trends that can guide long-term regional policies. Geographic distributions of publications in SSA indicated that Kenya led with 14.3%,

Nigeria 12%, South Africa 10%, Tanzania 8.5% and Ghana 7.6% of the research publications, respectively. Many other countries, such as Madagascar, Gabon, Democratic Republic of Congo, Chad, Niger, Central African Republic, Somalia, Benin, Cote-D'Ivoire, Togo, Rwanda, and Burundi were underrepresented in renewable energy publications. The reasons for the limited number of publications may be insufficient research funding and technical expertise, and absence of cooperation with regional and international organizations that facilitate research focusing on renewable energy. For SSA academic institutions, the challenge that may hinder peer-reviewed research in the field of renewable energy maybe a highly centralized institutional arrangement, limited responsibility for PhD supervisors, low impact research, and poor infrastructure. These challenges need to be addressed by SSA institutions for there to be any meaningful gain in research in renewable energy.

The network and density visualization of publication's abstracts revealed that most of the terms pertained to biomass-related topics. A noteworthy insight was the fact that there has been a shift of the discussion from the traditional sources of biomass (woodfuel and charcoal) to more efficient biomass options such as bio-fuel crops. Although literature reviews account for 24% of publications, there was only one article using the quantitative review approach. This underscores the need to incorporate more quantitative reviews to assess renewable energy research undertaken in the region. Studies involving techno-economic analysis and socio-technical analysis collectively accounted for 17% of all studies. This could be attributed to development projects in SSA that are geared towards technical feasibility by engaging local communities. There are also many publications related to modelling methods (14%) to study trends in SSA also a considerable number of publications involving modeling approaches (14%) to study trends in SSA, related policies, projects and future scenarios of climate conditions.

The basic challenges the development of renewable energy in SSA are interconnected. This is evident as adequate research stems from enough funding that often results in bridging the technical gap in terms of manpower (skill), and information (data and awareness). However, this requires an appropriate policy framework, to use limited resources to maximize benefits and promote the development of renewable energy. Improved energy access through renewable energy will go hand in hand to enhance other aspects of Sustainable Development Goals (SDGs). This quantitative review presents a snapshot of the scope of renewable energy research that mostly covers the challenges, solutions, and focus of renewable energy.

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### **3. Factors affecting renewable energy consumption using Panel Data analysis in Sub-Saharan Africa <sup>2</sup>**

#### **3.1 Introduction.**

Energy remains essential to economic development, as modern comforts and industrial production processes primarily depend on energy (Shahbaz et al., 2015). As developing countries strive to bridge the development gap, they are faced with the key challenge of meeting their economic growth targets while considering the environmental costs (WEF, 2016). This growth goes hand in hand with the use of energy, leading to the question of how SSA will meet its future increasing energy needs. The need for energy to fuel economic growth in SSA is at a critical stage where the balance between mitigating climate change and the ability to employ scarcely available capital for clean energy ventures must be put in place (Wesseh and Lin, 2016).

Renewable energy technology has the capacity to bridge the energy access gap and foster economic growth, especially in Sub-Saharan Africa (SSA) where there are abundant untapped renewable energy resources, such as wind, geothermal, solar, and biomass (Mohammed et al., 2013). The advantage that SSA countries have over developed countries is that they can employ innovative technologies without having to follow the historical trajectory of energy systems that have resulted in negative environmental impacts. Several studies demonstrating the ability of renewable energy to improve energy security, provide socio-economic benefits, reduce local pollution, decentralize energy to remote areas, and mitigate climate change have been conducted (Inglesi-Lotz, 2016; Salim and Rafiq, 2012; Shahbaz et al., 2015). There is a consensus among many authors that the drivers behind different types of non-renewable energy consumption have

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<sup>2</sup> A modified version of this chapter has been submitted to the Renewable Energy Journal - Oluoch et al. *Investigating factors affecting renewable energy consumption: A Panel Data analysis in Sub-Saharan Africa* and is currently under review.

been explored extensively, whereas the drivers behind renewable energy remain unknown (Ito, 2017; Inglesi-Lotz, 2016; Salim and Rafiq, 2012). Also, Nyiwul et al., 2016 and Sardosky (2009) admit that while there has been active research in modeling the relationship between renewable energy consumption and income in developed economies, there remains a gap in the domain of renewable energy and technical efficiency in developing countries. Our study seeks to evaluate how renewable energy consumption can affect social, economic, and environmental factors.

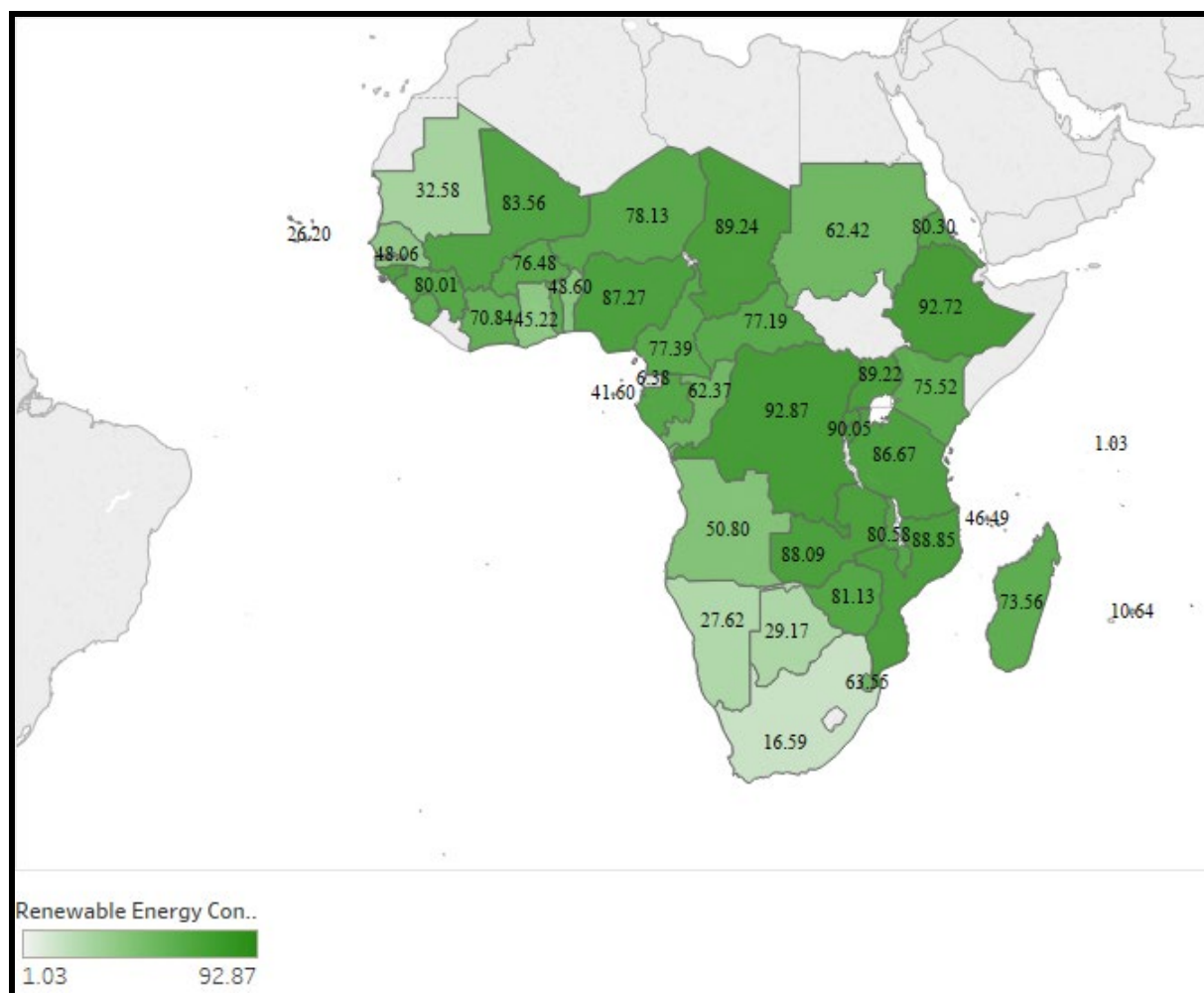
This present chapter aims to contribute to existing research by combining Economic (Total Labor Force, GDP per capita, Consumer Price Index, and Net Official Development Assistance), Social (Public Health Expenditure, Education Index, Life Expectancy Index, and Corruption Perception Index) and Environmental (Forest Area and CO<sub>2</sub> emissions) variables to analyze their contribution on renewable energy consumption. To the best of our knowledge, this chapter is one of the few in the field of renewable energy in SSA to investigate the effect of renewable energy consumption on such variables using the panel data approach (fixed and random effects model) and the 2SLS as a robust check for instrumental variables. Unlike other studies that have mainly focused on explanatory variables such as CO<sub>2</sub> emissions, economic growth, total labor force, and consumer price index, we expand this knowledge to consider unique explanatory variables such as Corruption Perception Index, Net Official Development Assistance, Public Health Expenditure, Life Expectancy Index, Education Index, and Forest Area. The need for many studies in the area of renewable energy and factors affecting it in SSA is driven by unique and interrelated factors such as renewable energy potential, energy access, rural population, governance, financial, and technical aid that differs from the rest of the world. It is important to understand the determinants of renewable energy consumption that can direct a suitable implication for energy policy. Therefore, empirical analysis can further help

policymakers from different SSA countries to formulate effective and practical policies to improve the use of renewable energy. The main objective of this second chapter is to examine the relationship between renewable energy consumption and economic, social, and environmental determinants by applying a panel data (fixed and random effects) framework in 44 African countries over a 25-year period.

## **3.2 Methodology**

### **3.2.1 Panel Data Regression Analysis Model.**

Panel data takes advantage of two-dimensional information by combining cross sectional and time-series data. We obtained data mainly from World Bank Data Indicators (WDI), while Education Index (EI) and Life expectancy Index (LEI) were drawn from UNDP development reports, and Corruption Perception Index (CoPI) drawn from transparency international database (TI, 2016; UNDP, 2016; WDI, 2016) (Table 3.1). We collected data from 44 African countries to achieve a comprehensive geographic distribution. The countries included are Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Republic of Congo, Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe. Countries such as Somalia, Liberia, Lesotho, and South Sudan were excluded due to lack of data. The data cover the period 1990-2014, giving a total of 1100 observations (Figure 3.1).



**Figure 3.1:** Map representing 44 selected countries for the study and their respective Renewable energy consumption as percentage total of energy consumption (RECT).

**Table 3.1:** Variables, Definition and Descriptive Statistics.

Variable/Acronym	Acronym	Definition	Obs	Mean	Std. Dev
Renewable energy consumption (% of total)	RECT	Share of renewable energy in total energy consumption.	1,087	69.577	25.012
Consumer Price Index	CPI	Measure of price level of energy.	982	68.571	36.207
GDP per Capita	GDPPCC	Sum of gross value added by producers in the economy divided by the population.	1,084	1512.424	2641.354
Total Labor Force	TLF	The economically active population for supply of labor for production of goods and services	1,072	6,280,243	8.58 x 10 <sup>6</sup>
Net Official Development Assistance	NODA	Measure of international aid flow.	1,096	5.53 x 10 <sup>-8</sup>	7.49 x 10 <sup>-8</sup>
CO <sub>2</sub> Emission (metric tons per capita)	CO2EMTPC	CO <sub>2</sub> emissions per capita.	1,092	0.844	1.735
Forest Area (% of land area)	FA	Assesses the growth or reduction of forest area	1,097	33.466	1.735
Rural population (% total)	RPperTotal	Refers to people living in rural areas as a share of total population.	1,097	64.506	15.146
(Public Health Expenditure % GDP)	PHE	Recurrent government spending on health.	1,100	2.405	1.261
Education Index	EI	Mean years of schooling index.	1,100	0.363	0.139
Life Expectancy Index	LEI	The number of years a newborn infant expected to live.	1,100	0.536	0.115
*Corruption Perception Index.	CoPI	A measure corruption levels in nations.	391	30.159	12.275

**Note:** Corruption Perception Index (CoPI) was used in the scenario analysis where the observations were for 22 countries over time period of 1998 to 2014.



### 3.2.2 Estimation procedures

Our methodology followed a similar approach to Azam (2016), in which they used the fixed-effect and random-effects model. When compared with cross-sectional data and time series data, panel data contains more degrees of freedom and more sample variability, thereby improving the efficiency of economic estimation. It reveals the dynamic relationship and relies on the differences between individuals to reduce the collinearity between the current variable and the lagging variable to estimate the unlimited time adjustment mode (Hsiao, 2016).

Panel data itself has its own limitations, as it is subject to endogeneity that can be addressed using methods such as the two stage least square (2SLS) (Lee, 2007). The 2SLS estimator allows observed and latent variables to be derived from non-normal distributions (Bollen, 1996; Ito, 2017).

As a robustness check, we independently conducted an instrumental variable estimation to avoid bias associated with correlation between the dependent variable and the error term (Ackah and Kizys, 2015). We conducted tests for endogeneity using the 2SLS instrumental variable approach to detect for valid instruments against the endogenous variables and overlying restrictions. Based on economic theory, we assumed that GDP, CPI, and TLF were endogenous variables. Renewable energy projects create employment that impact the economy, the linkages can imply some degree of endogeneity in the model. Since higher total revenue will put pressure on renewable energy consumption, TLF will stimulate GDP. CPI can also be endogenous to GDP as the economy depends on the cost of energy and will influence economic growth. Similarly, CPI will affect the total labor force, because low energy costs means greater purchasing power that may stimulate consumption.

We standardized our variables by obtaining their z-scores via rescaling the values to have a mean of zero and a standard deviation of one. We used the fixed and random effects tests for the main specification and scenario analysis with the Stata 14 statistical software. For the fixed effect test, we analyzed the impact of the variables that vary over time within the countries. For random effects, we tested whether the variation across the countries may have some influence on the dependent variable that was assumed to be random and uncorrelated with the independent variables included in the estimates. We used Hausman tests to determine whether fixed effects or random effects are used to if the unique error is related to the regression.

We constructed a panel model by using Renewable Energy consumption (RECT), as a dependent variable in response to factors described as:

$$\text{RECT} = f(\text{GDPPCC}, \text{CPI}, \text{TLF}, \text{NODA}, \text{CO2EMTPC}, \text{FA}, \text{PHE}, \text{RPperTotal}, \text{EI}, \text{LEI}, \text{CoPI}) \dots \dots \dots (1)$$

Then, we proposed a general model with the following specifications:

$$\text{RECT}_{it} = \beta_0 + \beta_{1i}\text{GDPPCC}_{it} + \beta_{2i}\text{CPI}_{it} + \beta_{3i}\text{TLF}_{it} + \beta_{4i}\text{NODA}_{it} + \beta_{5i}\text{CO2EMTPC}_{it} + \beta_{6i}\text{FA}_{it} + \beta_{7i}\text{PHE}_{it} + \beta_{8i}\text{RPperTotal}_{it} + \beta_{9i}\text{EI}_{it} + \beta_{10i}\text{LEI}_{it} + \beta_{11i}\text{CoPI}_{it} + \mu_{it} \dots \dots \dots (2)$$

Where the subscripts  $i$  and  $t$  denote the country and time respectively,  $\beta$  represents the coefficients for each explanatory variable, and  $\mu$  denotes the random disturbance term in the model and  $X$ 's are independent variables.

### **(i) Specification 1**

In specification 1, the dependent variable is the percentage of renewable energy consumption (RECT) of the explanatory variables listed below. From equation 1, there is no explanatory variable CoPI:

$$\text{RECT} = f(\text{CPI}, \text{GDPPCC}, \text{TLF}, \text{NODA}, \text{CO2EMTPC}, \text{FA}, \text{PHE}, \text{RPperTotal}, \text{EI}, \text{LEI})$$

**(ii) Scenario Analysis**

We conducted a scenario analysis to investigate the effect of corruption perception index on renewable energy consumption by introducing this new variable into our regression equation.

We adopted a balanced panel data set of 15 years (1998 to 2014) and 23 countries (Botswana, Cameroon, Chad, Democratic republic of Congo, Republic of Congo, Cote d' Ivoire, Ethiopia, Gabon, Ghana, Kenya, Malawi, Mozambique, Namibia, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and, Zimbabwe) due to available data for those countries in the Transparency international database.

This can be summed up as follows from equation 1.

$RECT = f(CPI, GDPPCC, TLF, NODA, CO2EMTPC, FA, PHE, RPperTotal, EI, LEI, CoPI).$

### 3.3 Results

#### 3.3.1 Instrumental variable tests for specification 1 and scenario analysis

Table 3.2 presents estimation results from the 2SLS model using the preliminary OLS to test for endogeneity and good instruments for both specification 1 and the scenario analysis. We observe that all the estimated coefficients (GDPPCC, CPI, TLF, NODA, and EI) are statistically significant at the 5% level except for LEI. For the scenario analysis, GDPPCC, NODA, EI, and COPI are statistically significant at the 1% level, and LEI, CPI, and TLF are significant at 5%. The p-value of the Durbin wu Hausman first-stage test of endogeneity is 0.00, indicating that endogeneity exists in both models. In the second stage test, all p-values of the Sargan test exceed the conventional significance level of 0.05, indicating the validity of the instruments, which in this case were CO2EMTPC, FA, RPperTotal, and PHE for both models.

**Table 3.2.** Result of 2SLS

Dependent variable: <b>RECT</b>		
Variables	Specification 1	Scenario Analysis
<b>GDPPCC</b>	-0.849*** (0.129)	-0.851***(0.1644)
<b>CPI</b>	-1.459*** (0.285)	-1.232**(0.484)
<b>TLF</b>	-0.717** (0.221)	-0.593**(0.212)
<b>NODA</b>	0.856*** (0.180)	0.59*** (0.175)
<b>EI</b>	0.331** (0.106)	0.452*** (0.174)
<b>LEI</b>	0.876 (0.118)	0.786** (0.399)
<b>CoPI</b>	-	-0.546*** (0.156)
Durbin (score)	Chi2(3) = 294.46	Chi2(3) = 191.622
p-value	p = 0.000	p = 0.000
Wu-Hausman	F(3,932) = 141.271	F(3,359) = 128.552
p- value	p = 0.000	p = 0.000
Hansen J test	Score chi2(1) = 0.1179	Score chi2(1) = 0.7035
p-value	(p = 0.7317)	(p = 0.4016)

**Notes:** \*\*\*p<0.01, \*\* p<0.05, \* p<0.10. Instrument variables are as follows CO2EMPTC, FA, RPperTotal and PHE in specification 1 and 2. The null hypothesis of the Sargan test is that the over-identifying restrictions are valid. Standard errors are reported in parenthesis.

### 3.3.2 Specification 1 and Scenario analysis

Both Specification 1 and Scenario analysis demonstrated that the estimators have a significant explanatory power based on the large F-statistic, and the overall adjusted  $R^2$  values for fixed effects estimators and random effects estimators (Table 3.3 and 3.4). The Hausman test determined a preference for the fixed effects model for both specification 1 and the scenario analysis. This means that the variation within the years may have some influence on the dependent variable that is assumed to be random and uncorrelated with the independent variables included in the estimates. Of the 10 explanatory variables, only 7 were statistically significant at the 95% confidence interval for specification 1. These include TLF, FA, and LEI with positive coefficients, GDPPCC, CPI, CO2EMTPC and EI with negative coefficients (Table 3.3). Of the 11 explanatory variables in the scenario analysis, only 8 were statistically significant at the 95% confidence interval. These include TLF and LEI with positive coefficients, and GDPPCC, CPI, CO2EMTPC, PHE, EI, and CoPI with negative coefficients (Table 3.4).

**Table 3.3:** Represents Fixed Effects and Random Effects regression for specification 1 (RECT) as dependent variable.

Variable	Fixed Effects Coefficients	P >  t	Random-Effects Coefficients	P >  Z
<b>GDPPCC</b>	-0.104 (0.0132)	0.000***	-0.107 (0.0133)	0.000***
<b>CPI</b>	-0.0768 (0.0148)	0.000***	-0.0754 (0.0145)	0.000***
<b>TLF</b>	0.2084 (0.0381)	0.000***	0.234 (0.0343)	0.000***
<b>NODA</b>	-0.00898 (0.00953)	0.346	-0.00984 (0.00966)	0.309
<b>CO2EMTPC</b>	-0.604 (0.0263)	0.000***	-0.590 (0.0257)	0.000***
<b>FA</b>	0.289 (0.101)	0.004**	0.273(0.0628)	0.000***
<b>PHE</b>	0.00386 (0.0119)	0.745	-0.00178 (0.0119)	0.881
<b>RPperTotal</b>	0.0455 (0.043)	0.290	0.0838 (0.396)	0.034**
<b>EI</b>	-0.214 (0.0337)	0.000***	-0.192 (0.0325)	0.000***
<b>LEI</b>	0.134 (0.0183)	0.000***	0.116 (0.0184)	0.000***
<b>Constant</b>	0.0362 (0.00768)	0.000***	0.0307 (0.0717)	0.669
R-sq Within	<b>0.6821</b>		0.6811	
R-sq between	0.4800		<b>0.5151</b>	
R-sq overall	0.5092		0.5393	
	F-statistic (10, 890)	190.96	Wald chi2(10)	1900.24
	Prob > (F-statistic)	0.000	Prob > chi2	0.0000
<b>Hausman Test</b>				
Ch-Sq Statistic	=	48.89		
Chi-Sq. d.f	=	10		
Prob > chi2	=	0.0000		

**Notes:** \*\*\*p<0.01, \*\* p<0.05, \* p<0.10. The values in the parenthesis are the corresponding standard errors.

**Table 3.4:** Represents Fixed Effects and Random Effects regression for Scenario analysis (RECT) as dependent variable.

Variable	Fixed Effects Coefficients	P >  t	Random-Effects Coefficients	P >  Z
GDPPCC	-0.0951(0.0275)	0.001**	-0.0799(0.0268)	0.003**
CPI	-0.0931(0.226)	0.000***	-0.0805(0.0216)	0.000***
TLF	0.337(0.0805)	0.000***	0.331(0.0646)	0.000***
NODA	-0.00329 (0.0131)	0.801	-0.003(0.0132)	0.955
CO2EMTPC	-0.285 (0.0939)	0.003**	-0.341(0.0747)	0.000***
FA	0.134(0.190)	0.483	0.232 (0.102)	0.023**
PHE	-0.0563 (0.0217)	0.010*	0.0524(0.0215)	0.015
RPperTotal	-0.148 (0.123)	0.230	0.0522 (0.0982)	0.595
EI	-0.256 (0.071)	0.000***	-0.192 (0.0642)	0.003**
LEI	0.0918 (0.0376)	0.015	0.081 (0.0362)	0.025**
CoPI	-0.0695 (0.0211)	0.001**	-0.0658 (0.0209)	0.002**
Constant	0.112 (0.0295)	0.000***	0.0976 (0.109)	0.373
<b>R-sq Within</b>	<b>0.3164</b>		0.3088	
<b>R-sq between</b>	0.5302		<b>0.6477</b>	
<b>R-sq overall</b>	0.5253		0.6357	
	F-statistic (11, 336)	14.14	Wald chi2(11)	201.30
	Prob > (F-statistic)	0.000	Prob > chi2	0.0000
<b>Hausman Test</b>				
Ch-Sq Statistic =	19.59			
Chi-Sq. d.f =	11			
Prob > chi2 =	0.0155			

**Notes:** \*\*\*p<0.01, \*\* p<0.05, \* p<0.10. The values in the parenthesis are the corresponding standard errors

### 3.4 Discussion

#### 3.4.1 Economic Indicators

We used GDP per capita (GDPPCC) as a proxy to measure the size of an economy and income. Greater levels of income are associated with an ability to bear high regulatory costs in terms of taxes and tariffs for power, guarantee higher support for the cost of public policies in promoting and regulating renewables, and the provide financial resources to implement renewables (da Silva et al., 2018; Marques et al., 2010). We expected that an increase in renewable energy consumption would increase the GDPPCC. An increase in energy has shown to be a positive driver for economic activities that result in economic growth (da Silva et al., 2018; Inglesi-Lotz, 2016; Salim and Rafiq, 2012). For specification 1 and scenario analysis, the coefficients were both negative and significant. The estimated coefficients for GDPPCC is -0.104 and -0.0951 respectively, meaning that for one-unit change in GDPPCC, the renewable energy consumption decreased by 0.104 and 0.0951 respectively. It was unexpected that renewable energy consumption would correlate negatively with GDPPCC. Even so, studies such as Kilinc-Ata (2016) support our findings, as they found that income measures such as GDPPCC will show a positive effect on renewable energy consumption for developed countries, but not for developing countries. Similarly, Nyiwul (2016) established that SSA's expanding renewable energy consumption was not strongly related to economic growth. On the contrary, Ackah and Kizys (2015), Asafu-Adjaye (2000), Sardosky (2009) and Shabbaz et al. (2015) found that GDPPCC has a positive and significant effect on the renewable energy consumption in SSA.

The negative value in our study can be attributed to two key factors that go hand in hand to plague the energy sector in SSA. These factors are low income levels among SSA residents especially in rural settlements (76% of total population), making it difficult for governments to



distribute electricity (Nyiwul, 2016; Kilinc-Ata, 2016), coupled with the high cost and unreliable supply of electricity, resulting in losses of up to 2-4% of GDP for most countries in SSA (APP, 2015). This has made electricity unaffordable to rural residents, which in turn have stifled revenue for existing renewable energy projects, often resulting in the lack of maintenance of aging energy plants (APP, 2015; Wesseh and Lin, 2016). Furthermore, the lack of economies of scale for existing renewable energy plants made many projects non-viable in the long term, often resulting in lack of maintenance of aging energy plants (APP, 2015). The relationship between limited power generation and low income is cyclical, turning energy inequality into slowing economic growth and investment (APP, 2015). Due to these factors, given that most SSA countries have not yet reached the level of economic development that allows for increased consumption of renewable energy, our results remain consistent.

Consumer price index (CPI) used as a proxy for energy prices is inversely related to renewable energy consumption. The estimated coefficients of specification 1 is - 0.077, and the estimated coefficient of scenario analysis is -0.093. Both are statistically significant. The results show that a unit change in CPI will reduce the renewable energy consumption of specification 1 by 0.077, and the scenario analysis will reduce the consumption of renewable energy by 0.093, thus supporting the expected results. The findings of Adams et al. (2016), Ackah and Kiszys (2015) and Asafu-Adjaye (2000) are like to our study. Whereas, Kahsai (2010) research is contrary to our findings, in which energy prices increased due to energy consumption. Renewable energy consumption should result in a decreased cost of power, especially after the projects have been commissioned and a return on investment is realized. Renewables are still more expensive than fossil fuels, due to long-term subsidies for fossil fuels in SSA, dependence on fossil fuel generators, inefficient transition systems, aging infrastructure, and outdated

technology (Wesseh and Lin, 2016). Consequently, SSA governments should implement policy initiatives that provide incentives for increased deployment of renewables. Incentives such as feed-in tariffs that ensure bulk production at a fixed price for economies of scale could attract investment and reduce price for consumers (Wesseh and Lin, 2016). Even so, our results demonstrated that renewable energy consumption has the capacity to reduce energy prices.

In the main specification and scenario analysis, the total labor force (TLF) is statistically significant. For specification 1, the TLF estimated coefficient is 0.209 and for scenario analysis, the TLF estimated coefficient is 0.337. The results show that changes in TLF per unit will increase renewable energy consumption by 0.208 units and 0.337 units, respectively. The outcome is the theoretically expected result, because renewable energy consumption should create jobs directly and indirectly. Direct opportunities involve employment in providing labor services for renewable energy power plants in day-to-day operations that require manpower. Whereas indirect employment opportunities arise from economic activities from auxiliary infrastructure, such as road networks, and manpower necessary to build and service power stations (Ackah and Kizys, 2016). The power supply brought by renewable energy projects also opens new markets in remote areas by providing self-employment opportunities, thereby stimulating the economy. This finding is consistent with the view of Nyiwul (2016), who reported that renewable energy projects have led to the expansion of the industry and created job opportunities. Policies that encourage deployment of off-grid renewables especially in remote areas will further increase employment opportunities.

### **3.4.2 Environmental Indicators**

Higher CO<sub>2</sub> emissions have raised concerns over adverse climate change, and the resulting measures involve the use of renewable energy. We expected a negative relationship

between renewable energy consumption and CO<sub>2</sub> emissions, mainly because renewable energy sources are usually less carbon intensive in comparison to their fossil fuel counterparts. From our results, renewable energy consumption was statistically significant in both the main specification and scenario analysis, and correlated negatively with CO<sub>2</sub> emissions per capita with one-unit change of CO<sub>2</sub> emissions per capita resulting in a decrease in 0.604 units of renewable energy consumption (specification 1) and 0.285 (scenario analysis). This expectation is consistent with the studies of Sardosky (2009), Ackah and Kizys (2015) and Marques et al., 2010, which modelled the effect of CO<sub>2</sub> emissions on renewable energy. Contrary results from Aspergis et al., 2018 suggested that SSA countries may not have reached the required level of GDP per capita that allows for reduced carbon emission levels. Carbon markets are expected to mobilize up to US\$100 billion per year by 2020 to support mitigation and adaptation activities in developing countries. Despite, these developments, SSA has only benefited from only 2.6% of Clean Development Mechanism (CDM) projects (Gujba et al., 2012; Mwirigi et al., 2014). Consequently, policy measures should ensure that renewable energy projects meet the stringent requirement of CDMs to tap into this funding mechanism.

In specification 1, the percentage of forest area to total land (FA) is statistically significant. The positive correlation between renewable energy consumption and FA is the theoretically expected outcome, as renewable energy consumption should provide a relief on forest resources that are mainly used as woodfuel. The estimated coefficient of 0.289 (specification 1) indicates that a unit change of FA will increase the consumption of renewable energy by 0.289 units. In SSA, between 80% and 90% of the population depends on the unsustainable use of traditional biomass (wood fuel and charcoal) for most of the household energy balance, resulting in environmental degradation of forestry resources (Bildiric and

Ozaksoy, 2016; da Silva et al., 2018; Mohammed et al., 2013). This dependency has put pressure on forests resulting in losses of up to two million hectares of forest between 2000 and 2010 (APP, 2015). Presenting challenges for sustainable biomass development in SSA, resulting in the need for a new image of biomass energy (Owen et al., 2013). Solutions lie in modernization of production, processing, distribution and consumption of biomass. To achieve these goals, policy measures involving information dissemination, strengthening regional economies, and capitalization of the latest technological advances need to be emphasized (Owen et al., 2013). In addition, the diversification of other renewable energy sources will lead to a shift away from traditional biomass, thereby alleviating the pressure on SSA forests (Jumbe and Mkondiwa, 2013; Mohammed et al., 2013). Currently, biomass for electricity production and as a source of transportation fuel has been underutilized in SSA, with only South Africa and Mauritius making significant strides (da Silva et al., 2018). Policies aimed at creating regional markets, streamlining regional policies and standardization of biofuels will lead to an increase in the development of renewables (Jumbe and Mkondiwa, 2013). Promoting the growth of non-food feedstocks such as *Jatropha* and switchgrass that can thrive on marginal lands can further protect environmental degradation and restore deforested environments (Onoji et al., 2015).

### **3.4.3 Social Indicators**

Human Development Index (HDI) is quantitative composite measure of human development for the countries well-being (Asare-Kyei et al., 2015). HDI computes GDP per capita as a measure of quality of life, life expectancy as a measure of health care, and literacy rates as a measure of education (Iddrisu and Bhattacharyya, 2015). For this study, we separately used the two components of HDI: Education index (EI) computing school enrollment and

literacy rates as a measure of education, and life expectancy (LEI) a measure of the lifespan of an individual in a given demographic setting (Anglina et al., 2016; Asare-Kyei et al., 2015).

Renewable energy consumption negatively correlated to EI in specification 1 and the scenario analysis, with one-unit change in EI resulting in a -0.214-unit change (specification 1) and -0.256-unit change (scenario analysis) in renewable energy consumption, respectively. Based on economic theory the finding was not the expected outcome, meaning that education as an essential component to promote renewable has been underutilized in SSA. Policy measures should include using education as a medium through which renewable energy consumption can be increased, through seminars, brochures, radio and TV programs that highlight the potential contribution of renewable energy to sustainable development and poverty alleviation, especially in remote areas (Owen et al., 2013). Furthermore, the education curriculum at primary, secondary, and tertiary levels should include renewable energy and energy conservation subjects in order to promote knowledge and awareness. This information is crucial for developing countries to integrate a culture that embraces renewables especially for young citizens who will be the future stakeholders and decision makers (Mohammed et al., 2015). Direct benefits of renewable energy to the education sector can be enhanced by introduction of solar panels and solar lanterns for schools in the remote areas. This will result in longer study hours and reduced costs of energy, as many rural schools depend on diesel run generators, tily lamps and lanterns that often have some adverse health implications (Mohammed et al., 2015).

Public Health expenditure percentage of GDP (PHE) and Life expectancy index (LEI) were social variables used as a measure of wellbeing in the society. In specification 1 and scenario analysis, PHE was negative, but not statistically significant. LEI was statistically significant for both specification 1 and scenario analysis, as LEI positively correlated to

renewable energy consumption, with one-unit change in LEI resulting in 0.134 unit change in renewable energy consumption for specification 1 and 0.0918 unit change for the scenario analysis. It should be apparent that an increased investment in renewable energy technologies should result in an increase in energy access and promote greater human development. In general, countries with higher life expectancy are also more concerned about the future of their descendants, which usually translates into a willingness to invest in environmental quality (Charfeddine and Mrabet, 2017; Pirologea, 2012). Hence, there should be a positive correlation between life expectancy index and environmental quality, which agrees with the findings from our study. However, a counter argument is that in countries with high life expectancy the ability and willingness to accumulate more physical goods results in increased environmental degradation (Charfeddine and Mrabet, 2017). Pirologea (2012) investigated energy consumption and human development in developing countries, and found that high values of HDI corresponded to greater energy consumption patterns. Clean and reliable energy influences the determinants of human development such as education, health, environmental safety, and gender equality (Pirologea, 2012). Aspergis et al., 2018 assert that renewable energy can play a role in improving healthcare by reducing air pollution levels and saving cost health care expenditures through solar installations at rural health facilities.

In both specification 1 and scenario analysis, the rural population indicator is negative. This was an unexpected outcome as we anticipated that renewable energy consumption to increase rural population. In SSA 612 million people still lack access to electricity, with 80% residing in the rural areas (da Silva et al., 2018). This is attributed to the high number of dispersed rural settlements that make it difficult to connect populations to the grid (Mohammed et al., 2013). The cost of connection to the grid in urban areas is cheaper, ranging from US \$ 500

in urban areas to US \$ 1,500 in rural areas in SSA, making provision of energy unattainable as most of the energy poor reside in rural areas (APP, 2015). Off-grid and small-scale renewable energy technologies are often inexpensive, making them a suitable alternative for rural settlements as they open opportunities for small and medium scale enterprises (SMEs). (Ackah and Kizys, 2015; Mukasa et al., 2015).

Corruption is the misuse of delegated public power for personal gain (Dogmus and Nielsen, 2020). The scenario analysis was modeled to include the indicator for corruption (CoPI) that was statistically significant. Based on economic theory, it was expected that renewable energy consumption should result in a positive increase in corruption perception index, as was the case in studies by Vasylieva et al., 2019 investigated the impact on renewable energy consumption on GDP and Corruption in European Union countries for 2000 to 2016. While this outcome may hold for developed countries, our study indicated that for one-unit increase in CoPI there was a decrease in renewable energy consumption by 0.0695 units. This outcome can be attributed to the mismanagement of utilities in SSA (Mukasa et al., 2015). Corruption will translate into the ineffective implementation of government programs, which will affect renewable energy development. Studies by Zhang et al., 2016 reveal that corruption has a negative effect on CO<sub>2</sub> emissions in lower emission countries but is insignificant in higher emission countries and may have a positive indirect effect mainly through its effect on GDP per capita. Other studies involving corruption perception index and economic growth have shown that the vice has a negative impact on the provision of public goods.

The control of corruption generated incentives for entrepreneurship and a positive impact on economic growth (Aparico et al., 2016; Bosco, 2016; Van Soest et al., 2016). Dogmus and Nielsen (2020) case study of corruption in the hydropower sector in Bosnia and Herzegovina a

transitional developing country, further reveals how bureaucratic process in procurement, tendering and managing hydropower projects, has created a safe space for corrupt actors (both government and private sector), that has resulted in unfinished projects. They established that factors that facilitate corruption are lack of existing legislation to monitor corruption; diverse and contradictory law in utilities that have different functions and interpretations; complex administrative processes; an absence or inadequacy of formal institutional arrangements; impunity due to players involved are in position of power (politicians, corporations, and civil-servants) and, nepotism and favoritism that encourage patronage (Dogmus and Nielson, 2020).

Similarly, management of power utilities remains the focus of the SSA energy crisis, mainly because utilities are mainly used mainly for political patronage and vehicles of corruption especially in centralized government settings (APP, 2015). However, recent research indicates that corruption is widespread even in decentralized government and public-private partnership, especially in developing countries studies (Fisman and Golden, 2017) Currently, many SSA power utilities recover only two thirds equivalent to 0.56% of SSA's GDP of revenue required for sustainable operations, resulting in cutbacks often disrupting the quality of service to existing customers (Eberhard and Shkaratan, 2012). There is a requirement for the privatization of utilities to reduce patronage and corruption. In addition, there is also need from oversight by the public and an improved process of transparency, in terms of documentation of processes that are open to further scrutiny through auditing mechanisms (Dogmus and Nielsen, 2020)

The caveats to studying corruption are lack records for researchers to collect data, as the actors are usually people in powerful position. In addition, sensitivity of information, illegality of practice and the safety of researchers and informants make reliable data collection process more complicated (Dogmus and Nielsen, 2020). In addition, critics of corruption perception index



believe that the index is flawed, easy to manipulate, and capable of only measuring proxies. Most SSA governments claim that the agency serves Western economic and geo-political interests (De Maria, 2008).

### **3.5 Conclusion and Policy Implications**

Overall, by considering the specification and scenario analyses conducted in the study, we found significant and large influence of renewable energy consumption on social, economic, and environmental factors. In other words, renewable energy consumption plays a vital role in increasing total labor force, forest area, and life expectancy, whereas it reduces income, carbon emissions, cost of living, corruption and education indexes. Our results suggest that SSA governments must encourage investments in renewable energy to promote economic growth that is sustainable and environmentally friendly to reduce carbon emissions. However, existing policies in SSA countries support fossil fuels, often resulting in market failure for renewables. As a result, governments in SSA countries can support renewables through tax cuts, grants and subsidies, thereby providing an enabling environment.

Introduction of market-based policies such as carbon cap and trading systems and renewable energy certificates should be promoted, as they will not only increase the overall share of renewable energy but also increase the efficiency of the energy sector by enhancing consumer participation in the energy market and providing much required capital for further investments. Privatization measures of the energy market in state-controlled utilities will go hand in hand in promoting much-needed efficiency and accountability. Regional integration policies should encourage trade between neighboring countries with energy surpluses to expand the scale of the economy to support the feasibility of capital-intensive projects, stimulate the economy, and increase income. There is strong evidence from our results that renewable energy consumption

has the capacity to decrease commodity prices and increase employment opportunities. This can be achieved by deployment of off-grid renewables, opening new markets in remote areas.

Stability and accountability in the institutions for the energy markets attract further investments in renewables. The management of public utilities requires good governance in order to provide a facilitative environment for implementation of renewable energy projects. The implementation of best practices can be further enhanced by promoting private-public partnerships that allow for market-based profit driven settings to be established, thereby providing responsible and reliable services. Depending on the type of renewable and policy arrangements, tools such as feed-in tariffs (FiTs) and the introduction of renewable energy license auctions can promote and simplify the competitive wholesale market structure for the renewable energy industry.

In view of the wide distribution of renewable energy potential in SSA, policies should be formulated to address the effective results of renewable energy development. Policies should provide economic incentives and subsidies that are geared towards making renewable energy cost more competitive to traditional fossil fuels. SSA governments should move with urgency to remove bottlenecks that curtail integration of renewable energy into the national grid. In order to unlock SSA's untapped renewable energy potential there must be a long-term policy commitment (strategic planning) that is a well-structured and efficient.

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#### **4. A Comparative Assessment of Public Awareness, Acceptance and Attitudes towards Renewable Energy in Kenya and Rwanda.** <sup>3</sup>

##### **4.1 Introduction**

Sub Saharan Africa (SSA) is the only region in the world where people without access to electricity is increasing, mainly due to the population growth outpacing the rate of electrification (Rodriguez-Manotas et al., 2018). However, there are some countries in this region with an emerging trend of an increased electricity access, including Kenya and Rwanda. Kenya's rate of access to electricity has been increasing at an impressive annual pace of 8%, from 16% in 2000 to 65% in 2018 (WDI, 2018; Power Africa, 2018). The remarkable growth rate can be attributed to political commitment and planning processes that are geared towards increasing electrification rate and expansion of renewable energy generation (Power Africa, 2018). On the other hand, Rwanda's population with access to electricity is 50% from 10% in 2009 (WDI, 2018; Power Africa, 2018). Progress in electricity access is due to the active efforts of the Rwandan government to eliminate the gap between high electricity costs and limited affordability through several energy policy reforms (REP, 2018). Rwanda's economic blueprint aims to develop into a middle-income economy. The goal is to achieve 100% electricity supply by 2024, 52% of which will be grid electricity and 48% will be off-grid electricity (Power Africa, 2018).

While achieving economic growth, the balance of providing more power to a growing population requires SSA to mix renewable energy sources in a sustainable manner. Yet, many countries in SSA continue to consume fossil fuels to meet their energy demands. In the 1990s

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<sup>3</sup> A modified version of this chapter has been submitted to the Scientific African Journal - Oluoch et al. *An assessment of Awareness, Acceptance and Attitudes towards Renewable energy in Kenya* and is currently under review.



and early 2000s, Kenya and Rwanda relied on diesel powered generators for electricity production due to irregular seasonal patterns resulting in unreliable rainfall that significantly impacted hydropower energy, which had been a dominant source of energy in both countries (KNEP, 2018; Uwisengeyimana *et al.*, 2016). Renewable energy has gained recognition as an effective alternative to fossil fuels due to its ability to be abundant and clean (Karasmanaki and Tsantopoulos, 2019). Global concerns and the push for reliable and clean sources of energy in the last decade have resulted in both countries making significant strides in deploying renewables. Currently, the share of energy from renewable sources in Kenya is 77%, with geothermal dominating at 44% and hydropower contributing 33% (Mokveld and von Eije, 2018). The target in Kenya is to increase the share of renewable energy sources in energy production from the 1990s level of 67% to 83% by the year 2020. This will mainly be facilitated by the introduction of about 2700MW of new generation capacity from 42 new power plants to add to the existing 2300 MW (Power Africa, 2018). In Rwanda, the total installed capacity stands at 218 MW, with 98 MW from hydropower (50%), 12 MW from solar (5.5%) and 103 MW from thermal plants (47%) (Power Africa, 2018; Rodriguez-Manotas *et al.*, 2018).

Public opinion on matters of renewable energy can assist in addressing challenges resulting from the uneven distribution of benefits and burdens of renewable energy development (Bergmann, 2006). Studies that attempt to identify levels of public awareness, acceptance, and attitudes towards different forms of energy technology have been conducted (Celikler, 2013; Curry *et al.*, 2005; Maula *et al.*, 2013; Zoellner *et al.*, 2008; Zyadin *et al.*, 2012; Karetepe *et al.*, 2014; Kermitsoglou, 2014)

According to the research of van Rijnsoever and Farla (2014), as science becomes more accountable to the public, studies addressing public acceptance are becoming more prominent. In

addition, since many new sustainable energy technologies are publicly funded, public opinion should be considered, because public adaptation to energy policies is critical to its successful implementation. Karytsas and Theodoropoulou, 2014 assert that public awareness of renewable can promote social recognition and overall improvement in consumer energy behavior. Other studies have demonstrated that there is a strong relationship between renewable energy implementation and public awareness, policy structure, and market characterization (Assali *et al.*, 2019). Such research of public opinion and knowledge about energy-related issues can often help policy makers and stakeholders formulate sensible policies suitable for solving public concerns (Ediger *et.al.*, 2018). Furthermore, as government legitimacy depends on public support, public perception is critical in policy making (Chen, *et al.*, 2015). Policy makers have thus realized the need to seek public acceptance as a core factor in the formulation and implementation of policies that guide renewable energy development.

Whereas, studies in developed countries have investigated the public opinion towards renewable energy with the goal of understanding the barriers around the socialization of renewable energy (Shahbaz *et al.*, 2015). For SSA countries, such research remains a challenge. Ediger *et al.*, 2018, agree that public concern over energy supplies, prices, sustainability, and efficiencies has emerged globally, yet in terms of publication the knowledge seems to be largely concentrated in the West (North America and Europe), with other areas lagging. In Kenya and Rwanda, there is still a lack of literature about awareness, acceptance, and attitudes towards renewable energy. In both countries, literature on renewable energy development tends to focus on the technological and power supply aspects of renewable energy, with rather few studies that investigate the social and environmental effect of renewable investments (Abdullahi, 2011; Mohammed *et al.*, 2013; Uwisengeyimana *et al.*, 2016). This translates to a lack of highly

relevant public perspective that is important for designing a suitable policy to guide renewable energy development. There is a need for an approach that will focus on the social aspects of renewable energy development.

Chapter 4 investigates the level of awareness, attitudes, and acceptance of the public towards renewable energy sources (wind, solar, geothermal, hydropower, and biomass) with Kenya and Rwanda as case-studies. This will be a representative case study for SSA, as it will present an example of the renewable energy scenario for many countries in SSA in terms of government structure, renewable energy portfolios. In addition, it will reveal unique structure of policy scenarios through comparative analysis of the two countries, to determine the new information that these countries need to make renewable energy a success. This study will be one of the first to give a comparative examination of the relationship between awareness and attitudes towards renewable energy, while exploring other socio-demographic factors in SSA. The case of Kenya and Rwanda is particularly interesting due to their renewed commitments to diversify their energy portfolio, increase investments in renewable energy, and develop their energy policy over the last decade, resulting in significant strides in renewable energy development (APP 2015; KNEP, 2018; REP, 2018).

## **4.2 Methodology**

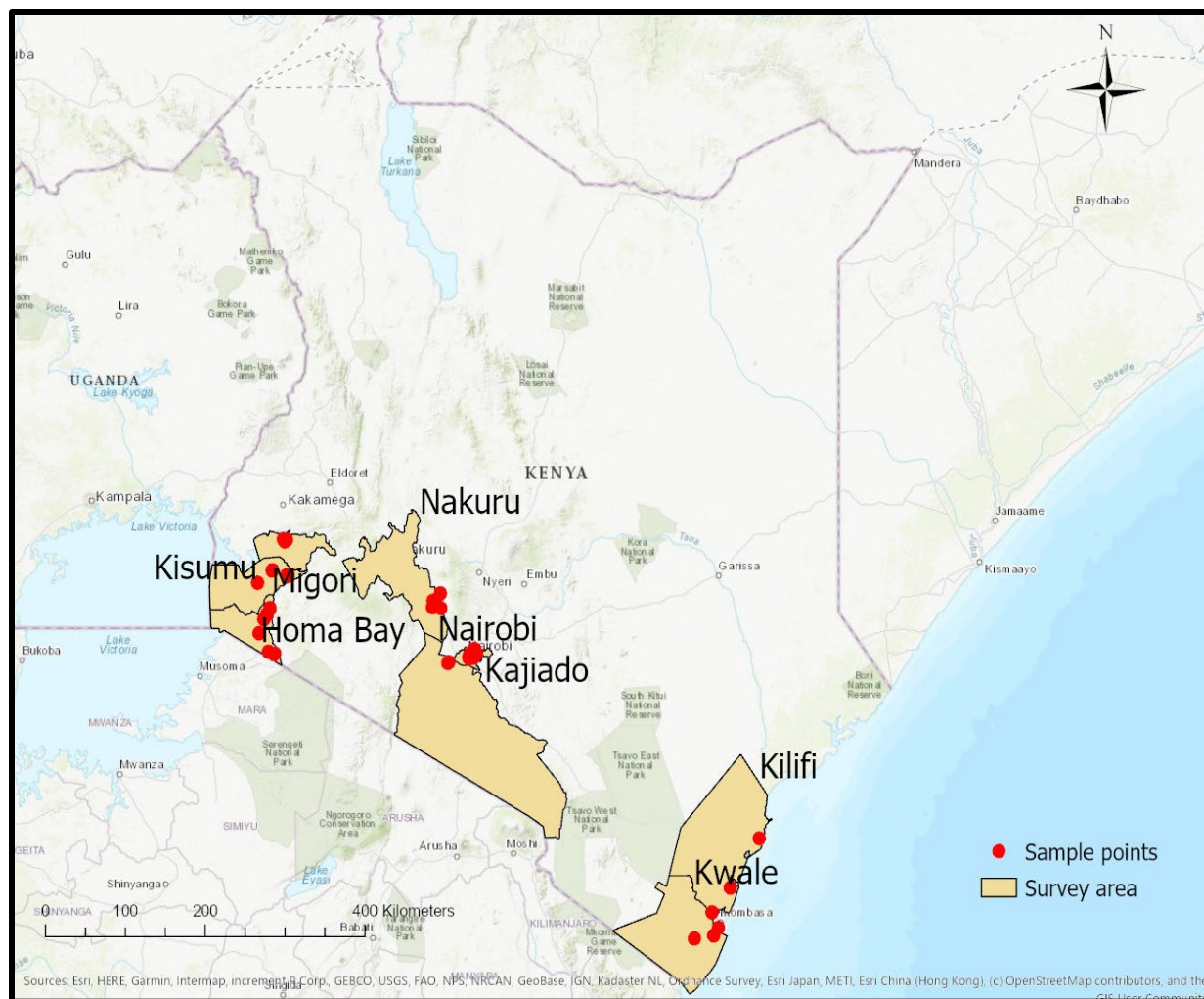
### **4.2.1 Sampling Framework.**

We chose the sample design based on recent census data from Kenya National Census Bureau (KNSB, 2018) and National Institute of Statistics, Rwanda (NISR, 2018) respectively. The desired target population was the household, composed of geo-demographic categories representing population samples of 18 years and older. We adopted the random stratified sampling technique that organizes the sample frame into sub-grouping that are internally

homogenous to ensure that sample selection is well distributed across important population sub-groups. This involves selecting the sample in successive steps using the hierarchical geographic units for which Kenya/Rwanda is divided into. It was necessary to treat the administrative regions such as provinces/counties(districts)/locations(sector)/sub-locations(cells)/villages as domains of interest (Table 4.1). For Rwanda we sampled all the 5 provinces, from each province we randomly selected three districts while considering the urban and rural distributions of the population. The village is the smallest unit from which the enumerators selected every third household, and the head of the household was selected as a respondent to ensure the sampling is random. For Kenya, 9 counties from the 47 possible counties, while considering the urban and rural distributions of each county. Three constituencies were randomly selected from the county, resulting in a total of 72 villages from which about 20 households were drawn (Figure 4.1).

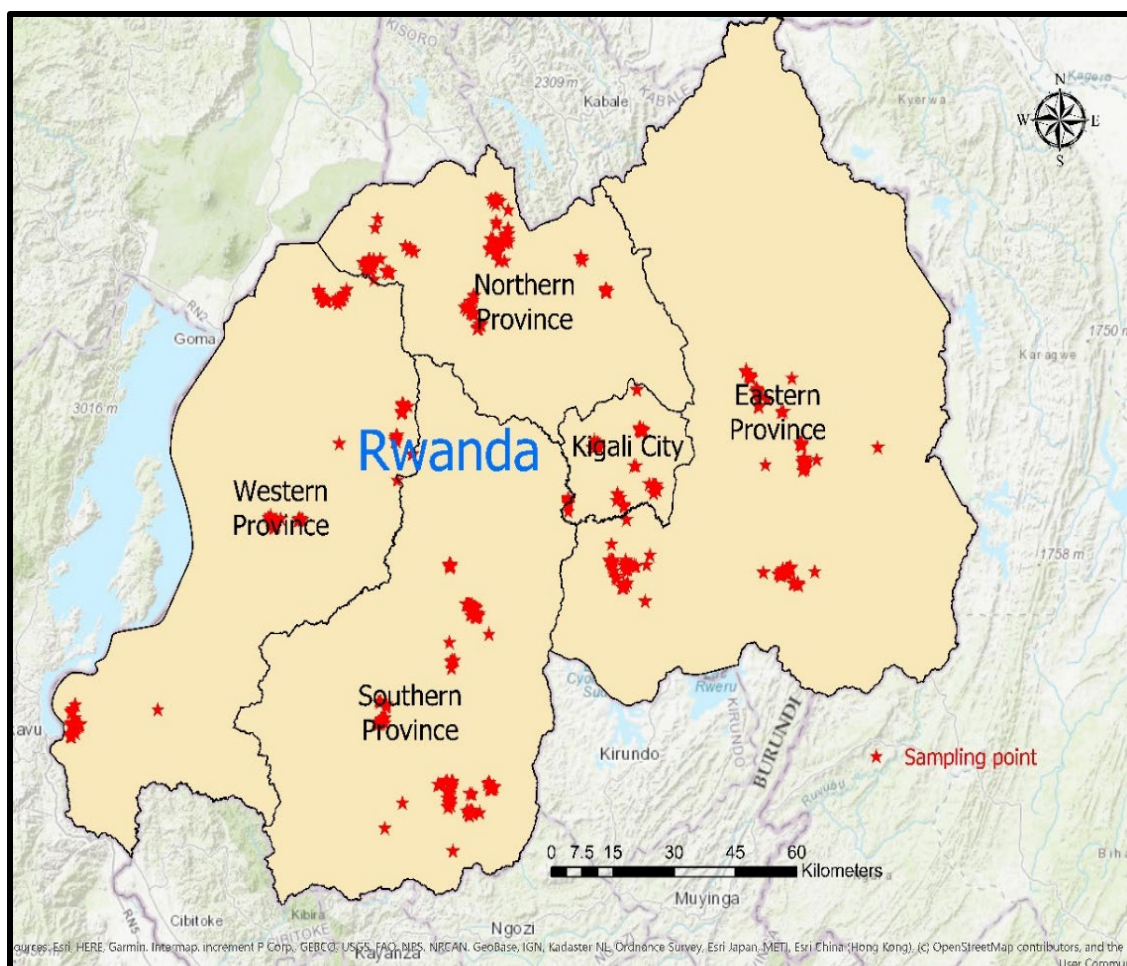
**Table 4.1.** Sampling framework

<b>Households Administrative units</b>	<b>Kenya</b>		<b>Rwanda</b>	
	Sampled	Total	Sampled	Total
<b>Province</b>	3	8	5	5
<b>County/District</b>	9	47	22	30
<b>Constituencies/Sectors</b>	25	290	47	416
<b>Wards/Cells</b>	72	1450	130	2184
<b>Respondents per Ward/Cell</b>	20		15	
<b>Total sampled</b>	1020		1006	



**Figure 4.1:** Survey area and sample points for Kenya.

For Rwanda the samples were drawn from all the 5 provinces, from which a total of 22 Districts, 47 sectors, 74 cells and 130 villages were enumerated with approximately 15 households for each village (Figure 4.2).



**Figure 4.2:** Survey Area and sample points for Rwanda.

#### 4.2.2 The Questionnaire and survey design

The questionnaire consisted of three parts. The first part included a brief introduction to the survey, background information on renewable energy, and government policy towards increasing renewable energy to enhance the respondents' understanding of the goal of the survey. This was followed by the second part that had questions assessing the respondent's awareness, acceptance, and attitudes towards renewable energy. In this section, the respondents were asked five questions, of which two were related to awareness, two questions related to acceptance of renewable energy, and one question related to attitudes towards renewable energy which was further explored using the ordered logistic regression as noted by Arikawa et al., 2014 and

Karlstrom and Ryghaug (2014). For the fourth chapter, we ordered the sample population based on their attitudes towards different energy types as the dependent variable using the STATA 15 for statistical analysis. The dependent variable was based on a five-point Likert scale ranking the respondent's attitude as very negative, negative, neutral, positive or very positive. Overall, we reclassified the ranking into three main outcome categories (negative, neutral and positive) for clearer analysis, because some choices had fewer responses. The independent variables included level of awareness, gender, age, the highest education achieved, and residence (Table 4.1). Awareness was grouped into two categories scaled from 1 to 6, with any scores below 3 classified as Not Aware and scores above 3 classified as Aware.

$$A_i = \alpha + \beta X_i + \gamma Z_i + \varepsilon_i$$

In the expression above, the variable  $A_i$  an attitude variable, which represents the category selected by the subject  $i$  as shown in the Table 1 below. We assume that socio-demographic variables, and the awareness factors discussed in the previous section determine the level of attitude towards renewable energy given by the equation above.  $X_i$  is a vector of socio-demographic variables and  $Z_i$  is the vector for other variables such as the level of awareness, residence, and education with corresponding parameters of  $\beta$  and  $\gamma$  respectively. It is assumed that the error term  $\varepsilon_i$  follows the standard normal distribution and  $\alpha$  is the intercept. The last part contains socio-economic information of the respondent (Table 4.2).

**Table 4.2:** Variables encoded in STATA.

Variable Name	Coding	Type
Dependent (Attitudes) $A_i$	1 = “Negative”, 2 = “Neutral”, 3 = “Positive”	Ordinal
Independent variables		
Awareness	1 = “Not Aware”, 2 = “Aware”	Ordinal
Gender	1 = “Female”, 0 = “Male”	Nominal
Age	Median age of respondents	Interval
Education	1 = “Primary”, 2 = “Secondary”, 3 = “Polytechnic”, 4 = “College & above”.	Ordinal
Residence	1 = “Rural”, 0 = “Urban”	Nominal

### 4.2.3 Data Collection and Analysis

The survey was distributed in-person, as mail, telephone, and internet infrastructure are limited, especially in the rural and peri-urban settlements. We collected the data in August 2019 for Kenya and in October 2019 for Rwanda using the Kobo Collect mobile application that automatically records the survey responses into a Microsoft Excel spreadsheet and thus eliminating the need for data entry. A sample of 1020 was randomized by age, gender, and geographical area, after discarding a total of 66 responses that were considered non-responses. Descriptive statistics were applied to all survey variables. In addition, the chi-square  $\chi^2$  independence test was also used to investigate the possibility of statistically important differences between the sample population and the total population.

## 4.3 Results and Discussion

### 4.3.1 Socio-Demographic Characteristics.

A total of 1086 in-person interviews were conducted for a month beginning in August 2019 for the Kenyan scenario. After missing and inconsistent answers were removed, 1020 responses (94.11%) were found to be valid for further examination. For Rwanda, 1022 in-person interviews were conducted in the month of October 2019, from which 1006 responses (98.43%) were found to be valid for further examination. The representativeness of the sample for the population was tested with the Pearson chi-square  $\chi^2$  independence test for the socio-



demographic variables for both countries. Table 4.3 presents the average sample values of several socio-demographic characteristics and their corresponding average values from statistical data (KIHBS, 2016; NISR, 2018; WPRR, 2018; and WDI, 2018). Tests for both countries indicate that the sample and population have a goodness of fit for most of the socio-demographic factors. At a 1% significance level, the evidence for rejection of the null hypotheses of the equality of means was found for annual household income, percentage rural population, and percentage electricity access for rural population.

**Table 4.3:** The comparison of the socio-demographic factors in the sample data and the corresponding population data.

	Rwanda			Kenya		
	Sample	Population	$\chi^2$ test	Sample	Population	$\chi^2$ test
Sample size	1006	12,785,472		1020	52,573,973	
Gender (% of females)	58.35%	51.8%	***	53.47%	50.3%	***
Age (median)	35.5	31.43	***	35.5	35.5	***
Age (mean)	39.4	35.71	***	35.74	39.2859	***
Household size (mean)	4.54	4.3	***	4.66	4.44	***
Annual household income	\$358.72	\$441.45		\$1661.	\$1254.54	
				0		
Marital status (% married)	63.32%	47.4%	*	60%	60.8%	***
Education.	10.43%	7%	***	27.75%	11%	
Rural population (%)	69.48%	83%		64.57%	73%	**
EA total population (%)	49.4%	30.0%	*	50.29%	65%	**
EA for rural population (%)	34%	18.0%	*	26.55%	17%	

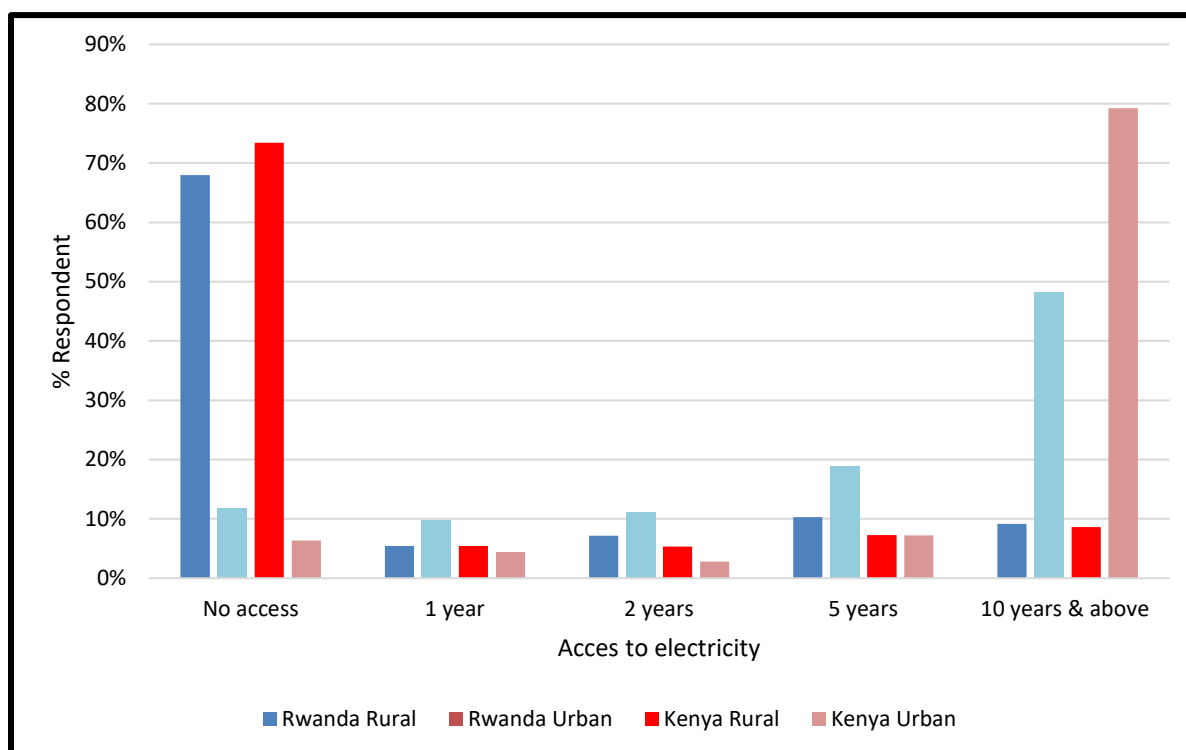
The population data is from WPRP 2018, KIHBS, 2016 and WDI (2018). \*indicates significance at 1% level, \*\* indicates significance at 5% level, \*\*\* indicates significance at 10%.

#### Notes

- Annual household income (mean in Ksh and Rwf respectively converted into 2019 USD)
- EA (Electricity access).
- Education % college degree.
- Population Age Median and mean adjusted to fit sample demographics.

### 4.3.2 Electricity access in Rwanda and Kenya

The first question was to inquire about the respondent's access to electricity. From our results, it is evident that electricity access in both countries has been increasing steadily for both results, it is evident that electricity access in both countries has been increasing steadily for both countries. Figure 4.3 shows the comparable electricity access of rural and urban residents in Rwanda and Kenya. Rural residents for Rwanda (74%) and Kenya (68%) show a higher percentage without access to electricity than their urban counterparts.



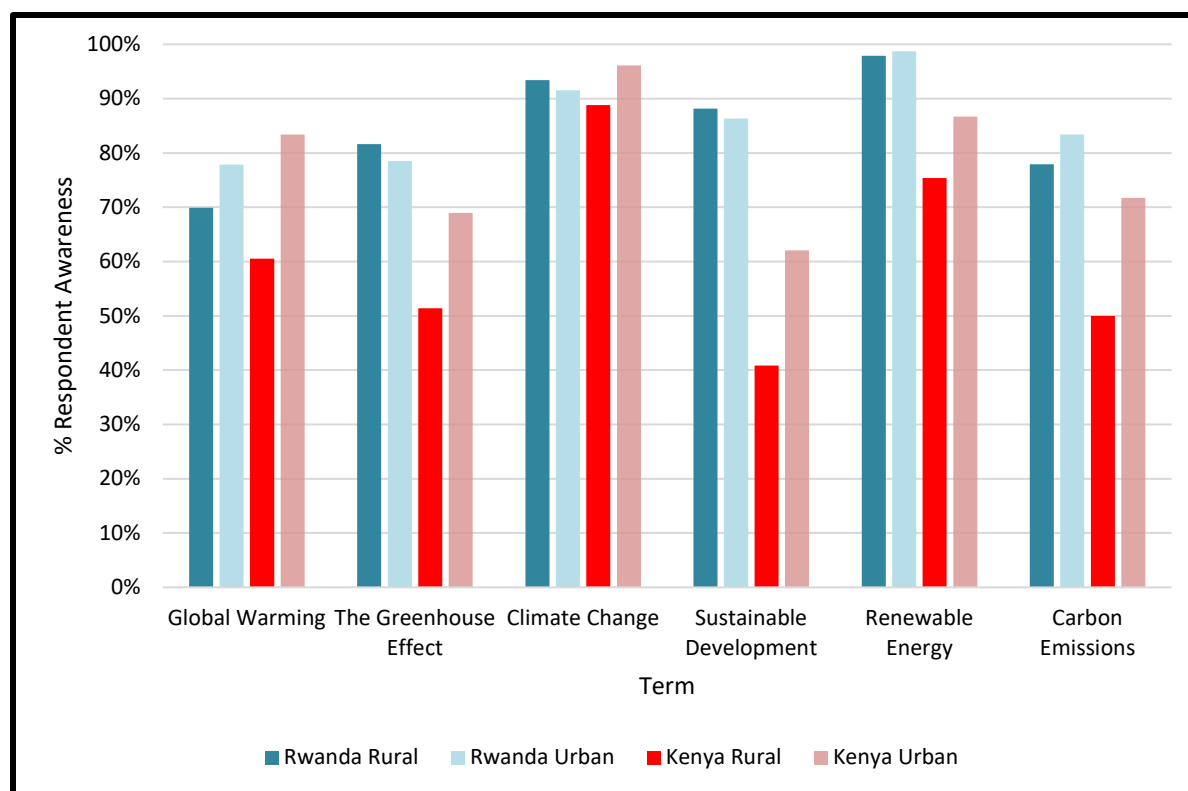
**Figure 4.3:** Percentage respondent duration of access to Electricity in Rwanda and Kenya (Urban/rural comparison).

### 4.3.3 Survey responses related to awareness and acceptance to renewable energy

In the second part of the questionnaire the survey, participants were asked questions about their awareness and acceptance of renewable energy. One question pertained to the level of awareness of respondents to general terms related to renewable energy debate, such as renewable energy, global warming, climate change, sustainable development, and carbon emissions.

According to the survey, the term that Kenyan respondents were most aware of was “climate change” with 91% of the respondents indicating being aware of this term, constituting 89% from rural and 96% from urban areas. The term that Kenyan respondents were least aware of was “sustainable development” with 48% of the respondents indicating awareness for this term, out of which 41% was from rural and 62% from urban areas respectively (Figure 4.4). In the case of Rwanda, respondents were most aware of the terms ‘renewable energy’ (98.5%), ‘climate change (92.5%),’ and ‘sustainable development (87%) respectively. For all the terms, urban residents in Kenya and Rwanda have a higher level of awareness than their rural counterparts.

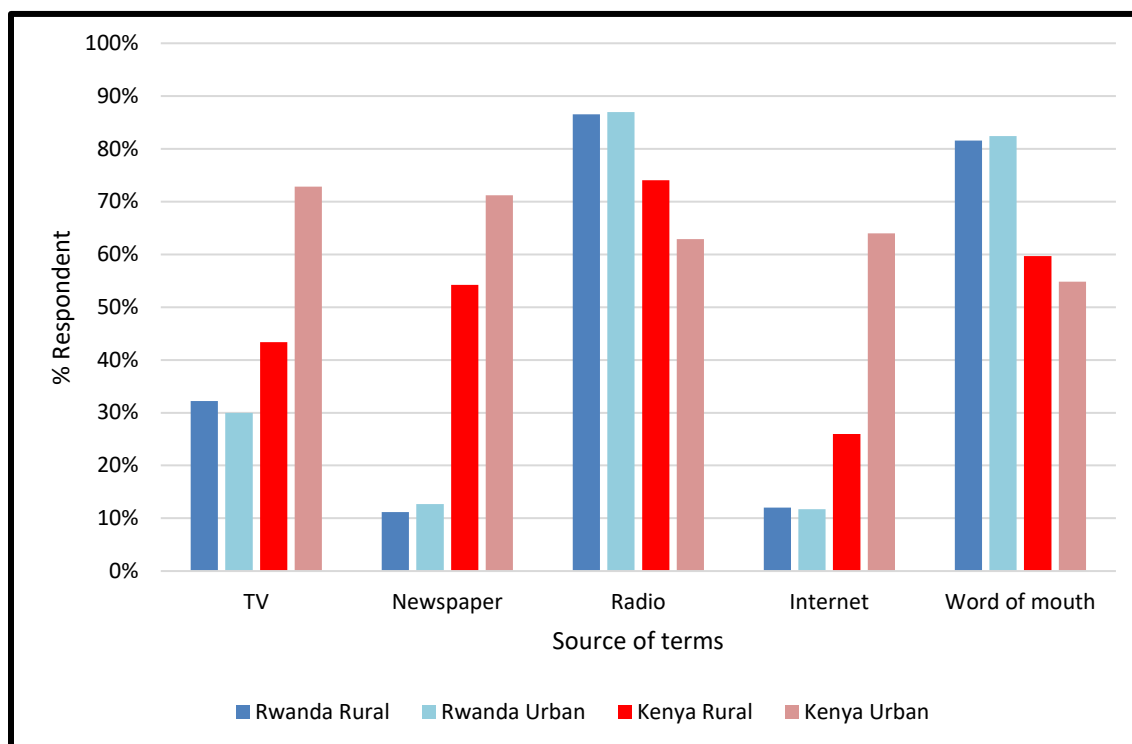
A comparative analysis between the two countries show that the rural residents of Kenya have the largest differences (20%) across all the awareness terms. In contrast, Rwanda’s rural respondent’s awareness levels are almost the same as urban residents, with a maximum difference of 5%. This in part could be attributed to the size of the country, Rwanda being a relatively smaller country (26,338 km<sup>2</sup>) than Kenya (580,367 km<sup>2</sup>) is also more densely populated with a population density of 525 people per km<sup>2</sup> as compared to Kenya (94 people/km<sup>2</sup>) (KNSB, 2018; NISR, 2018). This means that rural and urban populations are relatively undispersed as compared to their Kenyan counterparts. As a result, any awareness campaigns or knowledge dissemination processes in Rwanda are bound to be more effective in terms of reaching both rural and urban residents. On the other hand, Kenya will need more resources to reach remote areas, explaining the disparity in awareness between rural and urban residents. This finding is further supported with the results in the second question, where respondents were asked in what form of media, they first heard terms stated in the first question (Figure 4.5).



**Figure 4.4:** Before today, which of the following terms were you aware of?

Radio is the main source of information on renewable energy related terms in the two countries, followed by word of mouth and newspapers. Television and internet were the least popular forms of media in both countries. In Kenya urban respondents differed from their rural counterparts as they heard the terms mainly from television, followed by newspapers, and internet. There are no significant differences between rural and urban residents in Rwanda. In general, for both countries urban residents tend to indicate an increased use of television and internet as sources of renewable energy terms. This outcome was like studies by Ediger *et al.*, (2018) that investigated Turkish public preferences for energy, their findings indicated an increase in the use of television and internet/social media as information sources on energy issues and a corresponding decrease in newspapers. Kenyan residents show a greater use of internet, newspapers, and television as compared to Rwandan residents. Rwandan residents

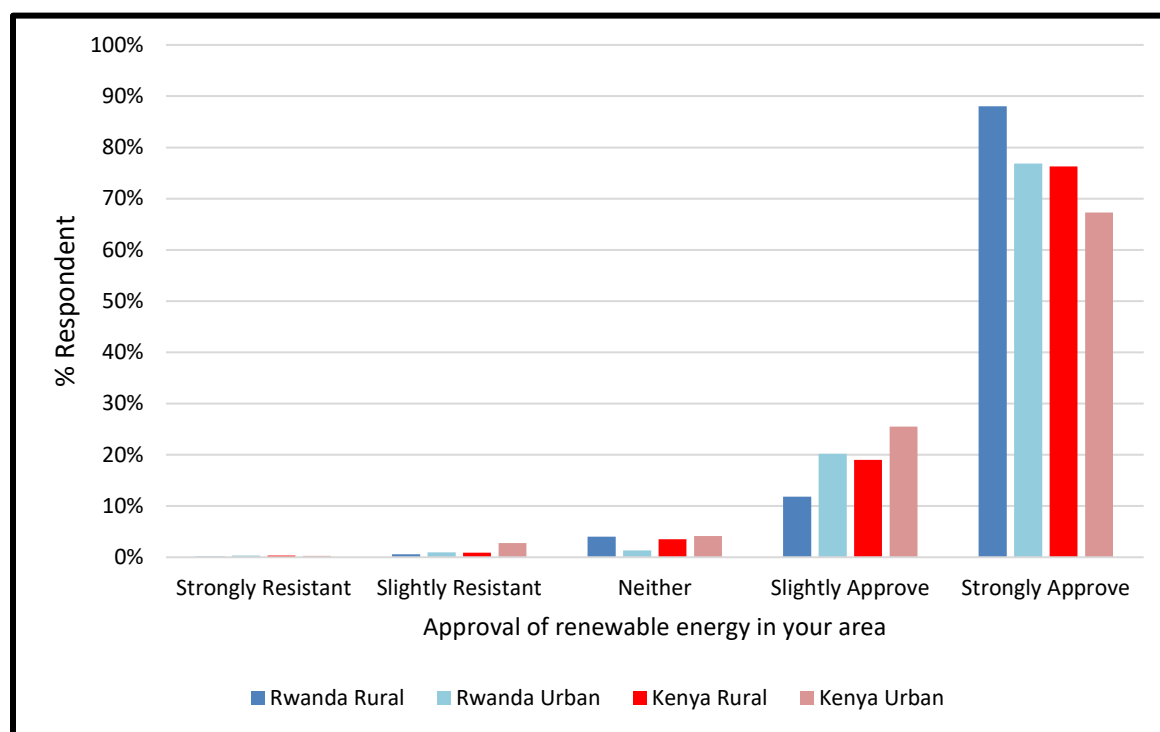
indicate a far greater preference for radio as their source of information as compared to Kenyan residents. For rural respondents, the most popular source of information on awareness was radio, followed by word of mouth, newspaper, television, and internet. This could be attributed to many rural respondents not having access to electricity and electrical appliances such as televisions and computers. As a result, respondents from rural areas rely mostly on radio and word of mouth as a source of information for renewable energy. Moreover, radios are relatively cheaper and can be powered by batteries or solar as opposed to television and computers in areas that lack access to electricity. Radio networks also cover remote areas of the country whereas television networks are mostly confined to urban areas so having television may not be effective as a source of media in rural areas.



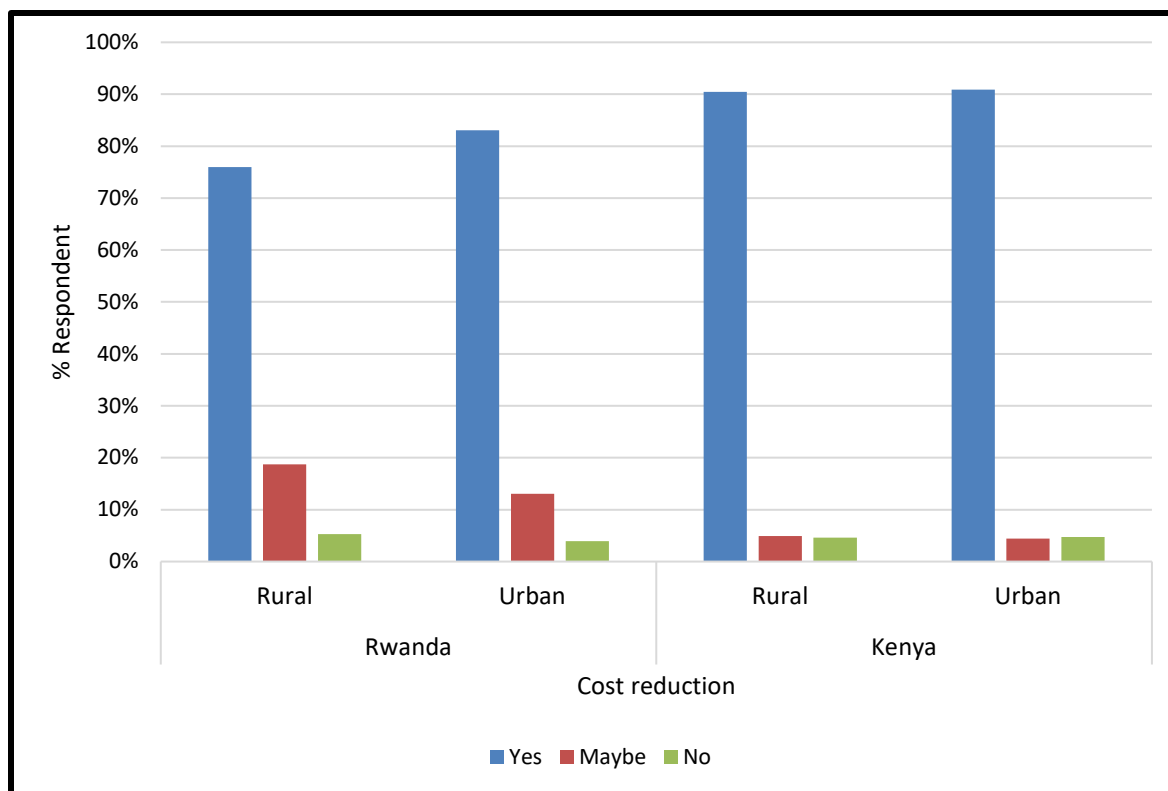
**Figure 4.5:** Generally, where did you hear of the terms in Figure 5.

In the third question, the respondents were asked about their approval of development of renewable energy their area of residence (Figure 4.6). The most salient finding was that 73% of

the respondents in both countries strongly approve the development of renewable energy. A further comparison of approval level between urban and rural residents for both countries indicated that rural residents strongly approved renewable energy development in the area at 82% as compared to urban residents at 72%. It appears that there is an appeal for renewable energy, as no respondent indicated a strong resistance to this technology. In contrast, rural residents in Rwanda had the highest approval rate for renewable energy at 88%. A follow up question assessed respondents' view of whether renewable energy has the capacity to reduce the cost of electricity (Figure 4.7). To this end nearly 88% of the respondents believe that renewable energy has the capacity to reduce the cost of electricity for both countries, with Kenyan residents showing higher values as compared to Rwandan respondents.



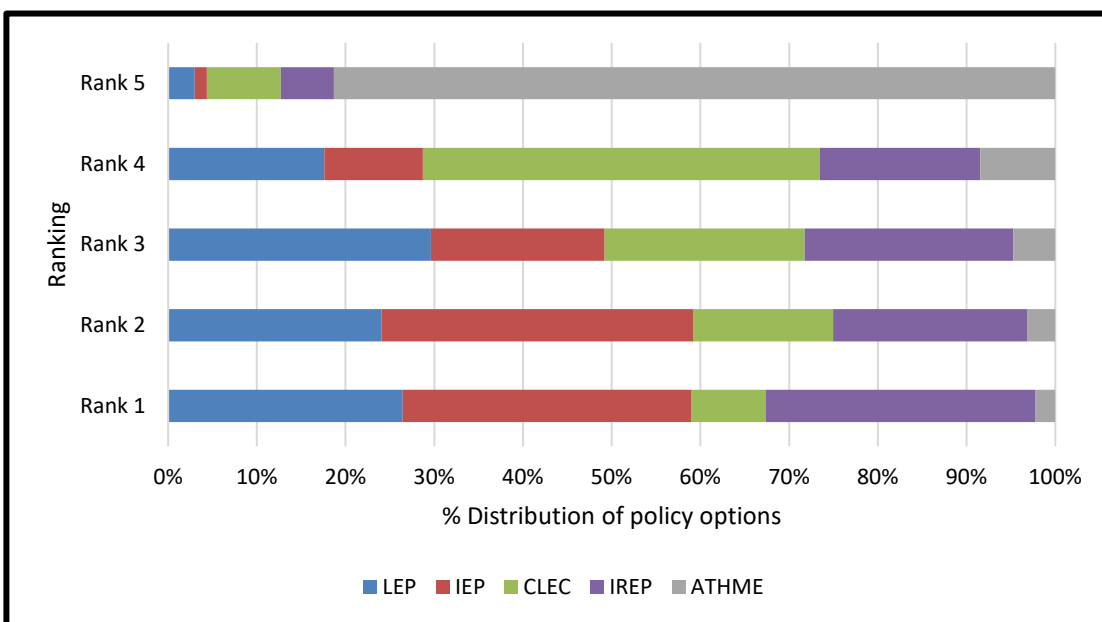
**Figure 4.6:** Would you approve of a renewable energy project was developed in your area?



**Figure 4.7:** Do you feel renewable energy sources will reduce the cost of electricity?

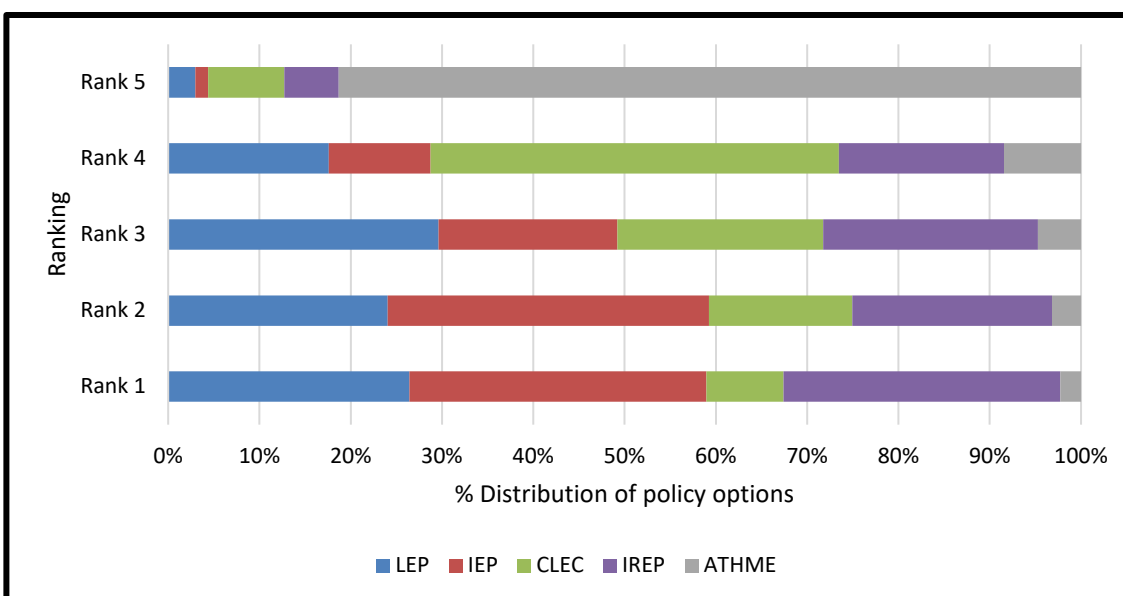
In the fourth question, the respondents were asked to rank five hypothetical policy options in order to further test for acceptance of renewable energy (Figure 4.8 and 4.9). Given the ever increasing demand for electricity and the growing concern about energy issues, it was critical to assess different policy options such as keeping electricity prices low, investing in renewable energy projects, increasing electrification programs, enacting additional taxation on households consuming a lot of electricity, and launching campaigns encouraging people to consume less electricity. These policy options were summarized and taken from the Kenya National Energy Policy document (KNEP, 2018) and Rwanda Energy Policy document (REP, 2018). In response to this question, Kenyan respondents ranked investing in renewable energy projects as the most important policy priority (40%), followed by lowering electricity prices (33%), increasing electrification programs (19%), launching campaigns encouraging households

to consume less electricity (6%), and enacting additional taxation on households consuming more electricity (3%). On the other hand, Rwandan residents placed increasing electrification prices (33%) at the highest priority policy option, followed by increasing renewable energy programs (30%) and lowering electricity prices (26%). Key concerns were the reduction electricity prices and the role of renewable energy in providing affordable electricity. Based on this policy concerns, respondents were further asked about the likelihood of experiencing energy shortages in their respective countries within the next 10 years (Figure 4.10). Respondents from Rwanda were more hopeful of their country not experiencing energy shortages than their Kenyan counterparts, with 79% respondents from rural and 56% from urban areas believing that energy shortages were unlikely. Kenyan respondents in general (54%) felt that Kenya was more likely to experience energy shortages.



**Figure 4.8:** Please rank the following government policy options in the order in which you would support them (Kenya).





**Figure 4.9:** Please rank the following government policy options in the order in which you would support them (Rwanda).

**Notes**

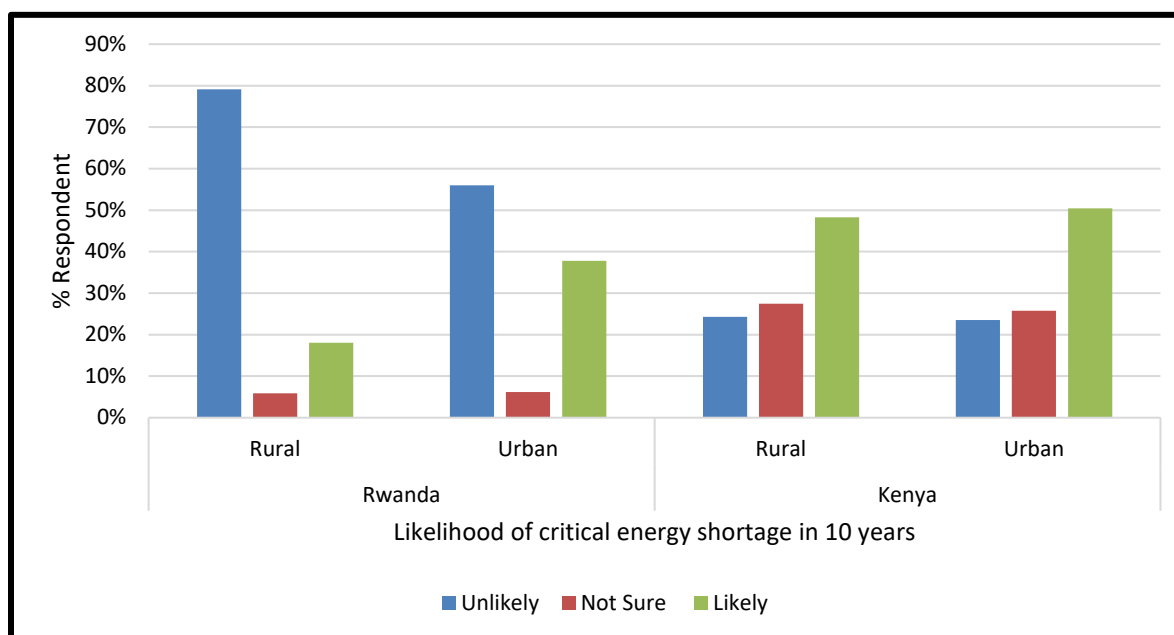
\***ATME:** Additional taxing on households who consume a lot of electricity

**CLEC:** Campaigns encouraging people to consume less electricity

**LEP:** Keeping electricity prices low

**IREP:** Investing in renewable energy projects

**IEP:** Increasing electrification programs.



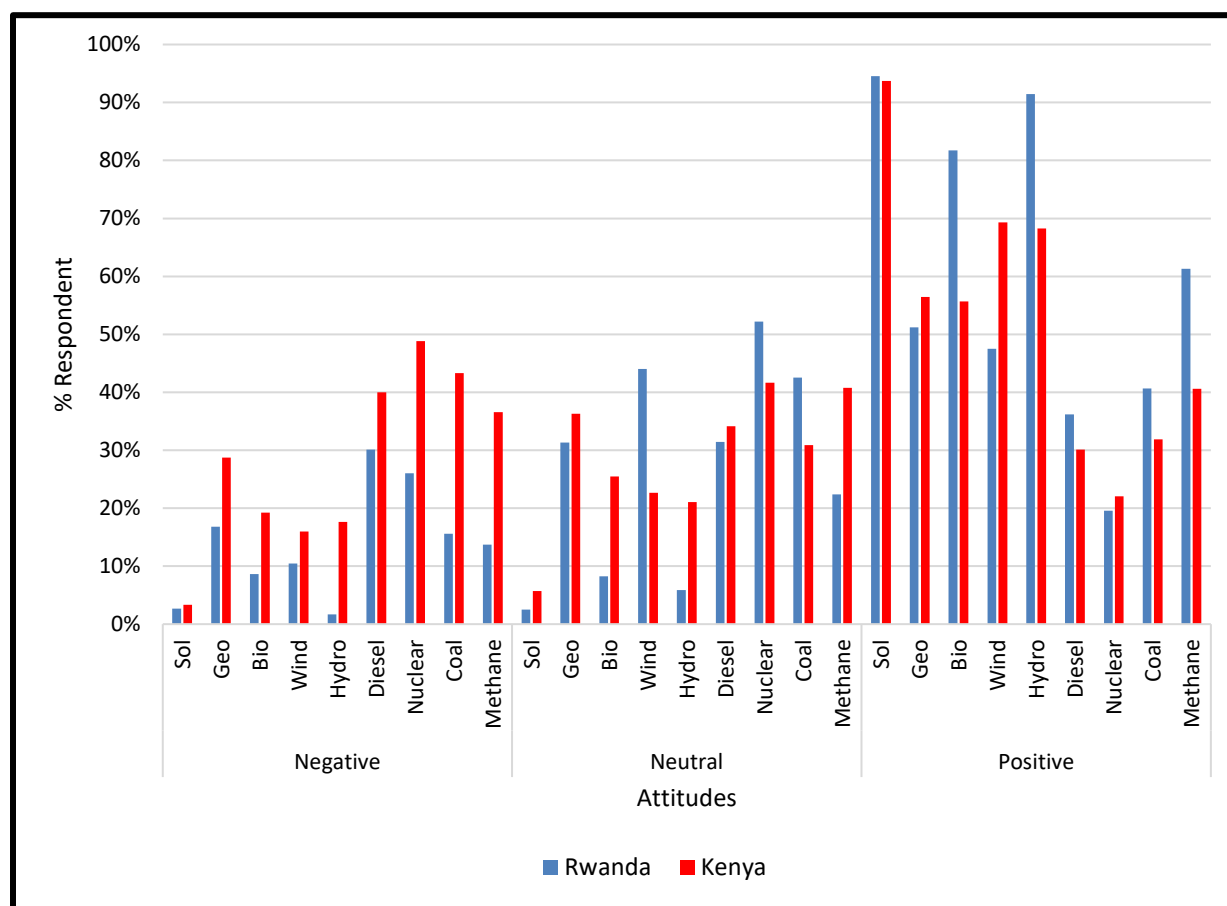
**Figure 4.10:** What is the likelihood of Rwanda/Kenya having an energy shortage in the next 10 years.

#### 4.3.4 Respondent attitudes to different types of energy

In this section, respondents were asked about their attitudes towards different sources of energy, including renewables and other sources of energy, such as diesel-powered plants, nuclear, coal, and natural gas. The question was considered appropriate as it was a general question, yet created an array of options to respondents based on their understanding of diverging concerns regarding different types of energy. Results shown in Figure 4.11 indicate that renewables received the highest percentages of respondents with positive attitudes in both Kenya and Rwanda with solar (94%), hydro (80%), biomass (69%), wind (58%) and geothermal (54%). This contrasted with other sources of energy having lower percentages (methane (51%), coal (36%), diesel (33%) and nuclear (21%). It is notable that highest ranking positive attitude for non-renewable energy (methane) was still lower than the lowest ranking positive attitude for a renewable energy (wind and geothermal).

Furthermore, wind and geothermal had the greatest number of respondents that indicated a neutral attitude with scores of 33% and 34% respectively. This was comparable to nuclear energy (42%), methane (41%), and diesel (34%) and coal (31%). Most of the Rwandan respondents had a neutral attitude especially for wind and geothermal as compared to their Kenyan counterparts. The neutral attitudes were mainly evident among respondents when a source of energy was not present in the respective countries, indicating that the presence of energy type guides the attitude towards it. For negative attitude, other sources of energy dominated with nuclear at 37% followed by coal(29%), diesel(35%) and methane (25%), whereas for renewable sources solar had the lowest percentages of respondents having a negative attitude at 3% followed by hydro(10%), wind (13%), biomass (14%) and geothermal(23%). Based on percentage scores, most of the respondents have a positive attitude towards renewable

energy. Hence, more effort is needed to be directed towards developing renewables as there is already an overwhelming support for the technology.



**Figure 4.11:** What is your attitude towards the following energy sources?

#### 4.3.5 The role of awareness and background variables on attitudes towards renewables.

We were interested in further exploring the attitudes of renewable energy technologies (Solar, Geothermal, Wind and Biomass) with the certain socio-demographic variables such as gender, age, residence, and electricity bill paid by respondents. To this end, we utilized an ologit regression analysis with attitude as the dependent variable and awareness as independent variables among the socio-demographic variables as explained in section 4.3.1. The ologit regression is important for distinguishing portions of the population that may have differences in attitudes. In addition, as shown in Tables 4.5 and 4.5, ologit regression makes a connection

between attitude and awareness. the ologit regressions enable an association between attitudes and awareness.

**Table 4.4:** Ologistic regression for renewable energy by type (Rwanda)

	<b>Solar</b>	<b>Geothermal</b>	<b>Biomass</b>	<b>Wind</b>
<b>Ordered Logistic</b>				
Awareness	1.021(0.373)*	1.389(0.203)***	1.617(0.224)***	1.270(0.213)***
Gender	-0.052(0.292)	-0.023(0.125)	0.135(0.176)	-0.181(0.149)
Age	0.008(0.0109)	0.013(0.005)*	-0.007(0.006)	-0.002(0.005)
Education	-0.068(0.165)	-0.217(0.077)**	-0.156(0.103)	-0.027(0.719)
Residence	0.516(0.303)	0.050(0.139)	0.125(0.194)	0.153(0.138)
Number of obs	1006			
Pseudo R2	0.0226	0.0323	0.048	0.0224
Log likelihood	-238.438	-970.285	-541.761	-927.156
<b>Marginal effects outcome (Negative)</b>				
Awareness	-0.025(0.009)*	-0.184(0.027)***	-0.113(0.017)***	-0.113(0.019)***
Gender	0.001(0.007)	0.003(0.016)	-0.009(0.013)	0.016(0.011)
Age	-0.0002(0.0002)	-0.002(0.0006)*	0.0005(0.0004)	0.0001(0.004)
Education	0.001(0.004)	0.029(0.010)**	0.011(0.007)	0.0024(0.007)
Residence	-0.014(0.009)	-0.006(0.019)	-0.009(0.014)	-0.0139(0.281)
<b>Marginal effects outcome (Neutral)</b>				
Awareness	-0.022(0.008)	-0.163(0.028)***	-0.10(0.017)***	-0.204(0.037)***
Gender	-0.001(0.006)	0.003(0.015)	-0.008(0.011)	0.029(0.0204)
Age	-0.0001(0.0002)	-0.001(0.0005)*	0.0004(0.0003)	0.0003(0.0007)
Education	0.001(0.003)	0.025(0.009)*	0.009(0.006)	0.004(0.012)
Residence	-0.0122(0.07)	-0.006(0.016)	-0.008(0.012)	-0.024(0.021)
<b>Marginal effects outcome (Positive)</b>				
Awareness	0.047(0.017)**	0.347(0.051)***	0.214(0.029)***	0.317(0.053)***
Gender	-0.002(0.013)	-0.006(0.031)	0.018(0.024)	-0.045(0.031)
Age	0.0003(0.0005)	0.003(0.001)*	-0.0009(0.0008)	-0.0004(0.001)
Education	-0.003(0.007)	-0.054(0.019)*	-0.021(0.0136)	-0.006(0.018)
Residence	0.026(0.017)	0.013(0.035)	0.017(0.026)	-0.038(0.034)

**Notes:** Robust standard errors corrected in parenthesis.

\*\*\*, \*\* and \* indicate significance at the 1%, 5%, and 10% levels.

Rwandan respondents with higher awareness towards renewable energy terms are more likely to have a positive attitude towards solar, geothermal, wind, and biomass. This was an expected outcome. For solar, the marginal effect's outcome shows that as awareness increases by one unit the respondent is 2.5% less likely to be in the negative category and 4.3% more likely to be in the positive category. For geothermal, as awareness increases by one unit, the respondents

are 18.4% less likely to be in the negative category, 16.3% less likely to be in the neutral category, and 24.7% more likely to be in the positive category. In the case of biomass, as awareness increases by one unit the respondents are 11.3% less likely to be in the negative category, 10% less likely to be in the neutral category, and 21.4% more likely to be in the positive category. Wind energy indicates that as awareness increases by one unit, the respondents are 11.3% less likely to be in the negative category, 20.4% less likely to be in the neutral category, and 31.7% more likely to be in the positive category. The variables for gender and residence were not significant at any level for all the energy types. The education and age variables were significant only for geothermal source of energy. Within this category, the coefficient was positive for age and negative for education for the ordered logistic regression as well as the marginal effect outcomes. Overall, the marginal outcome for other variables, was not significant for most energy types and only significant for the awareness variable.

**Table 4.5:** Ologistic regression for renewable energy by type (Kenya)

	<b>Solar</b>	<b>Geothermal</b>	<b>Biomass</b>	<b>Wind</b>
<b>Ordered Logistic</b>				
Awareness	-0.765(0.424)*	0.888(0.213)***	0.020(0.222)	0.577(0.230)**
Gender	0.058(0.335)	-0.437(0.198)**	-0.218(0.192)	-0.678(0.218)**
Age	0.014(0.016)	-0.006(0.008)	0.012(0.008)	0.007(0.009)
Education	0.358(0.164)**	0.187(0.098)*	0.082(0.096)	0.349(0.108)***
Residence	0.525(0.382)	-0.388(0.207)*	0.234(0.213)	-0.115(0.229)
Number of obs	1020			
Pseudo R2	0.0504	0.0752	0.0101	0.0581
Log likelihood	-148.07	-375.99	-403.112	-334.42
<b>Marginal effects outcome (Negative)</b>				
Awareness	0.004(0.003)	-0.041(0.011)***	-0.001(0.015)	-0.026(0.011)**
Gender	-0.001(0.002)	0.001(0.001)**	0.015(0.014)	0.030(0.011)**
Age	-0.001(0.001)	0.001(0.001)	-0.001(0.001)	-0.001(0.001)
Education	-0.002(0.001)	-0.008(0.004)*	-0.005(0.001)	-0.016(0.005)**
Residence	-0.003(0.002)	0.019(0.011)*	-0.016(0.014)	0.005(0.011)
<b>Marginal effects outcome (Neutral)</b>				
Awareness	0.043(0.024)*	-0.152(0.037)***	-0.003(0.032)	-0.076(0.031)**
Gender	-0.003(0.019)	0.074(0.033)**	0.031(0.027)	0.089(0.028)**
Age	0.001(0.001)	0.001(0.001)	-0.001(0.001)	-0.001(0.001)
Education	-0.020(0.009)	-0.032(0.017)*	-0.011(0.014)	-0.046(0.014)***
Residence	-0.028(0.019)	0.067(0.036)*	-0.033(0.030)	0.015(0.031)
<b>Marginal effects outcome (Positive)</b>				
Awareness	-0.048(0.026)*	0.193(0.046)***	0.04(0.048)	0.101(0.040)**
Gender	0.004(0.021)	-0.095(0.042)**	-0.046(0.041)	-0.119(0.038)**
Age	0.001(0.001)	-0.001(0.001)	0.003(0.001)	0.001(0.001)
Education	0.023(0.010)**	0.040(0.021)*	0.018(0.021)	0.062(0.018)***
Residence	0.031(0.021)	-0.086(0.046)*	0.049(0.044)	-0.020(0.041)

**Notes:** Robust standard errors corrected in parenthesis;

\*\*\*, \*\* and \* indicate significance at the 1%, 5%, and 10% levels.

Respondents with higher awareness towards renewable energy terms are less likely to have a positive attitude towards solar. This was an unexpected outcome and could be attributed to the introduction of standalone solar panels in rural areas that have always been prone to intermittent issues (Mohammed et al., 2013). In the case of geothermal and wind, respondents with higher awareness towards renewable energy terms are more likely to have a positive attitude. The coefficients of the variable for awareness for solar, wind, and geothermal were statistically significant at all levels except for biomass. For the marginal outcome, if awareness

increased by one unit, the respondent was 4.3% more likely to be in the neutral attitude category, and about 4.8% less likely to be in the positive category for solar. In the case of geothermal, as awareness increases by one unit the respondent is 4.1% less likely to be in the negative category, 15.2% less likely to be in the neutral category, and 19.3% more likely to be in the positive category. For wind, as awareness increases by one unit, the respondents are 2.6% less likely to be in the negative category, 7.6% less likely to be in the neutral category, and 10.1% more likely to be in the positive category. Monitoring awareness is vital for empowering people to choose appropriate energy behaviors on a day to day basis. The greatest obstacle to the growth of the renewable energy sector is public opposition to site selection in the UK (Ediger et al., 2018). Similarly, for Kenya, an example was the failure to reach consensus after a wind power project collapsed in a dispute between the local community and investors over land (Kazimierczuk, 2019).

For the education variable, respondents with higher education levels are more likely to have positive attitudes towards solar, geothermal, and wind energy at 5% and 10% statistical significance. Hence, for the marginal outcome, if education levels increase by one unit (for example secondary to college) the respondents are 23% more likely to be in the positive attitude category for solar, whereas for geothermal the values are 4.0% more likely, and wind 6.2% more likely to be in the positive attitude category. This suggests that as education levels increase, the renewable energy types become more favorable to respondents. For rural residents, the attitudes towards solar, biomass, and wind were not statistically significant. In the case of geothermal, respondents that lived in the rural areas were more likely to have a positive attitude towards geothermal energy. This could be attributed to the fact that geothermal projects in Kenya are often in rural settings, as a result rural residents are more familiar with its attributes. In favorable

areas, rural communities will be more open to supporting geothermal energy. Gender coefficient measured by (0 male and 1 female) was statistically significant and negative for geothermal and wind, whereas it was not statistically significant in the case of solar and biomass. Hence, female respondents were less likely to have a positive attitude towards both geothermal and wind technologies.

In the gender socio-demographic, the female population was less likely to have a positive attitude towards both geothermal and wind technologies. The underlying reasons for these attitudes may have not been covered due to the scope of the study but may pose an interesting discussion for future studies. Even so, female respondents from rural areas who were also in the lower education category indicated less awareness to renewable energy terms, which may have impacted their attitudes toward the two technologies. Attitudes are often influenced by other factors of widespread concern, such as environmental impacts, previous experiences, cultural norms, and aesthetic values (Keramitsoglu, 2016). As a result, the introduction of renewable energy information in civic programs and education curriculums will improve efforts towards raising environmental awareness.

#### **4.4 Conclusion and Policy implications**

The power sectors in Rwanda and Kenya represent milestones and challenges encountered by many countries in SSA in their efforts to build a green and inclusive economy. As Rwanda and Kenya seek to increase their renewable energy portfolios, there is a need to consider public participation. Towards this goal, we performed a nationwide survey to investigate Rwandans' and Kenyans' acceptance, awareness, and attitudes towards renewable energy. A sample of 1020 households from 8 counties, 40 constituencies and 72 villages/wards was used as a representative sample of the Kenyan population. While a sample of 1006



households from 5 provinces, 22 Districts, 47 sectors, 74 cells, and 130 villages in Rwanda were selected. This chapter supports the view that matters regarding the development of renewable energy, are closely monitored by the public and is one of the first of its kind that went further to include an analysis establishing a relationship between awareness and attitudes. The main conclusions from this chapter can be summarized as follows:

- Respondents in Kenya expressed awareness of terms related to renewable energy (69.6%) and Rwanda (85.5%). Awareness levels in Rwanda are greater due to the amount of resources required to inform public and means of communication by the government is slightly less as compared to Kenya
- Radio remains the most common source for renewable energy information for both Kenyan and Rwandan rural populations (70%), whereas television and internet remain the most common source of media for urban populations (73% and 64% respectively) in Kenya and Rwanda.
- Urban and rural respondents in Rwanda and Kenya strongly approve the development of renewable energy (73%) and believe that renewable energy will reduce the cost of electricity (91%).
- The most popular policy option was the development of renewable energy in the respondent's area (40%) followed by the reduction of electricity prices (33%) and increasing electrification programs (19%) in Kenya, whereas Rwandan residents placed increasing electrification prices (33%) at the highest priority policy option, followed by increasing renewable energy programs (30%) and lowering electricity prices (26%). It is evident that in Rwanda the cost of electricity remains higher than other East African

countries, thus many Rwandan respondents place a high priority for reduction of cost of electricity.

- There is a positive attitude towards renewables (68.6%) whereas for other forms of conventional energy, the positive attitude is lower (31.2%).
- There is a significant relation between all the independent variables (attitude, awareness and education) on attitude for all renewables (solar, wind and geothermal) except biomass.

Overall, the chapter has revealed that there is overwhelming support towards all renewables in both countries, with some small socio-demographic segments of the population having neutral or negative attitudes towards renewables. Consequently, policy initiatives should be rechanneled to the next step that should focus on integrating both public participation and private partnerships through innovative market technologies (off-grids and mini-grids) that will simultaneously provide energy access and new sources of income. As renewable energy deployment is bound to make a foothold in many communities, the next step of engaging the public will be to require their input in the process of assessing the benefits of different attributes of renewable energy technologies such as impacts on the environment, job creation, distance and visibility and ownership. The chapter will serve to raise awareness, improve public participation and individual responsibility that is geared towards the reduction of the effects of global and localized climate change.

Finally, the comparative approach used in our case-study to assess public view, serves to further highlight the existing barriers that limit public input in the larger context of renewable policy in SSA. The nature of the barriers can be cultural, political, economic, financial, regulatory, technical, and institutional. Even so, the finding from this case-study underscores the

need to scale up the studies in SSAs countries as well as other developing economies. The inherent collective knowledge from the public will assist to design cohesive policies that will safeguard the environmental, social and economic interests of the countries.

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## **5. Public preferences for Renewable Energy options: A choice experiment in Kenya <sup>4</sup>**

### **5.1.1 Introduction.**

The energy sector in Sub-Saharan Africa (SSA) offers a unique combination of transformative potential and attractive investment opportunities (Castellano et al., 2015). As recently as 2018, 63% of SSA's population had no access to electricity (da Silva et al., 2018; WDI, 2018). Currently, SSA contributes about 7.1% of global greenhouse gas (GHG) emissions, which is considered relatively small considering that it hosts 14% of the world's population (WDI, 2018). However, rapid population growth and an expanding economy could contribute to a significant increase in SSA's GHG levels and exacerbate climate change (da Silva et al., 2018; WDI, 2018). Furthermore, SSA countries remain some of the most vulnerable to climate change due to the lack of financial resources, high dependence on natural resources for agricultural production, and low technological advancement (Adzawla et al., 2019; Longa and Zwaan, 2017). SSA is at a critical stage where the balance between mitigating climate change and the ability to foster sustainable economic growth by utilizing scarcely available capital for clean energy ventures must be put in place (Mohammed et al., 2013). Many SSA governments have come to this realization and are developing policy that is increasingly open to the development of renewables through private-sector investments (Kazimierczuk, 2019; Pueyo, 2018). Renewables in SSA have the potential to reduce CO<sub>2</sub> emissions, bridge the energy access gap, and foster economic growth due to abundant untapped potential from wind, geothermal, solar, and biomass-based energies (Castellano et al., 2015; da Silva et al., 2018; Pueyo, 2018).

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<sup>4</sup> A modified version of this chapter has been submitted to the Energy Economics Journal - Oluoch et al. *Public preferences for Renewable energy options: A choice experiment in Kenya*. and is currently under review.



The electricity sector in Kenya is a prime example of the challenges that SSA countries encounter as they try to build green and inclusive economies (Pueyo, 2018). To meet these challenges, Kenya has shown political commitment and consistency in planning. This has resulted in the implementation of major reforms in the energy sector dating back to the 1990s (Kazimierczuk, 2019; KNEP, 2018). The emphasis on increasing Kenya's energy capacity has relied on attracting private sector participation, which has resulted in policy changes such as the introduction of Feed in Tariffs (FiTs) and wholesale market structure, which allows for auctions for wind and solar permits (Kazimierczuk, 2019; KNEP, 2018; Mokveld and Von Eije, 2018). This commitment enabled Kenya to achieve a 65% level of energy access, which was an improvement over 2000, when only 43% of the population had access to electricity (WDI, 2018; Pueyo, 2018).

Kenya has remarkable renewable energy resources, with its geothermal power dominating the total energy mix at 44%, followed by hydropower at 33% (Kazimierczuk, 2019; KNEP, 2018). The wind generation potential in Kenya is  $346 \text{ W/m}^2$ , which is considered one of the highest in SSA, due to excellent topographies that enable suitable wind speeds (Kazimierczuk, 2019). It is anticipated that between 19 to 25% of the country's energy demand will be met by wind technology by 2030 (Mokveld and Von Eije, 2018; Pueyo, 2018). Kenya is located near the equator, which has high insolate rate of  $4\text{-}6 \text{ kWh/m}^2$ , with a total potential for photovoltaic installations estimated at 23,046 TWh/year (KNEP, 2018). Kenya is one of the most well-served off-grid populations in the world, mainly due to advanced pay-as-you-go solar home systems and innovative business model for microgrid development (KNEP, 2018; Mokveld and Von Eije, 2018). Despite, these considerable achievements and vast potential, the challenge

remains in bridging the energy access gaps, increasing the renewable energy share, and increasing public participation at all levels of policy development.

### **5.1.2 Prior studies in choice experiments**

Government and societies will always face a real tradeoff when choosing the most beneficial source of energy. In order to make a sound choice, there must be a good understanding of social, environmental, and economic benefits and costs (Kosensius and Ollikainen, 2013). The use of choice experiment as an economic valuation tool facilitates the estimation of trade-offs between goods, allowing for policy alternatives to be evaluated and respondents' preferences to be assessed (Kruger, 2006).

Several studies have explored preferences for different forms of renewable energy technologies and their impacts using multinomial logit (MNL) and/or Random Parameter Logit (RPL) models. Bergmann *et al.*, 2006 explored the landscape, wildlife, air pollution, and employment impacts of wind power in Scotland. While O'keefe, 2014 investigated important features of different renewable energy projects in the United States. The findings from the two studies suggest that environmental attributes significantly impact the public acceptability of renewable energy projects. Ku and Yoo (2010) focusing on similar renewable energy attributes to Bergmann *et al.*, 2006 found preferences for solar to be more heterogenous across respondents. Scarpa and Willis (2010) assessed the household Willingness to Pay (WTP) for renewable energy micro-generation technologies in the United Kingdom (UK). Their findings indicated that although older households are reluctant to adopt micro-generation technology, the choice of primary heating is not affected by age. A study by Susaeta *et al.*, (2009) assessing public preferences for forest biomass based energy in the Southern United states, established that preferences for environmental attributes are heterogenous as respondents are willing to pay for

ethanol blends of 10% to facilitate the reduction of CO<sub>2</sub> and improvement of biodiversity. Salm *et al.*, 2016 analyzed the risk-return preferences for renewable energy retail investors in Germany. The study shows that respondents are sensitive to the minimum holding period and issuer of community renewable energy investment offerings.

From these examples, it is evident that global literature on renewable energy is expanding, with many non-market valuation studies applied to understand the value of renewable energy from both an environmental and social welfare perspective. However, to the best of our knowledge, literature on renewable energy development in SSA involving choice experiments is rare. For example, Abdullah *et al.*, 2011 investigated the willingness to pay for renewable energy for rural electrification in Kisumu District (Kenya) focusing on grid electricity and photovoltaic electricity. From their result, they established that respondents were more willing to pay for grid electricity services than photovoltaic electricity. In another study, Abdullah and Mariel (2010) discussed willingness to pay (WTP) for retail electricity in Kenyan rural households. They investigated the willingness to pay for the quality of electricity services and dependence on traditional fuels such as woodfuel. These examples underscore how studies with a choice experiment perspective in renewable energy have not been adequately covered in SSA, particularly in Kenya. Hence, there is lack of perspective of the public that is highly relevant for designing suitable policy that will guide renewable energy development for SSA countries.

In chapter 5, we examined the marginal valuation of economic, social, and environmental impacts of renewable energy sources (wind, solar, biomass [biofuel and biogas], and geothermal) using the choice experiment method in Kenya. Specifically, we determined how different attributes impact willingness to pay for renewable energy development. We also investigated how socio-demographic characteristics of the respondents (rural/urban residence, age groups,

and education) affect willingness to pay for certain attributes of renewable energy development. Currently, in Kenya there is no information available on the public preferences for characteristics of renewable energy production alternatives. Chapter 5 fills this gap by focusing on the key attributes of renewable energy development, which are essential for formulating appropriate policies. This was facilitated by considering attributes such as ownership and community job creation that are unique to the SSA scenario, allowing for effective trade-offs between the renewable energy attributes. The analysis was carried out using the MNL and RPL framework to allow for possible preference heterogeneity across individuals.

## **5.2. Methods.**

### **5.2.1 Theoretical Framework**

Choice experiments are based on Lancaster's characteristics and random utility theory. This assumes that the utility an individual derives from a renewable energy project depends on the characteristics of the proposed renewable energy projects (attributes), individual characteristics, and the unobserved (stochastic) components (Lancaster, 1966; McFadden, 1976). MNL assumes that unobserved factors affecting the choice of alternatives are strictly independent of each other (Independence of Irrelevant Alternatives, IIA). One shortcoming to this approach is that it can be implausible in some cases, as the unobserved factors affecting the utility of the renewable energy projects considered are correlated with observable factors included as attributes in the experiment (Bergmann et al., 2006; Brennan and Rensburg, 2016). For our study, this shortcoming was addressed by using RPL framework to relax the assumptions that all respondents have the same preferences for the attributes being valued. The RPL is a more general version of the MNL, allowing unobserved factors to be random and to follow any

distribution and consider preference heterogeneity (Breana and Rensburg, 2016; Ek and Perrson, 2014).

The description of the theoretical framework applied for deriving the respondent's willingness to pay was based on Brennah and Rensburg (2016), Bergmann *et al.*, (2006) and Kuu and Yoo (2010) protocols summarized below. In each choice set, the respondent faced a choice between a set of three alternatives: Renewable energy project option A, Renewable energy project option B (each defined with different attribute levels), and Option C representing the status quo option (no renewable energy development).

In general, a respondent  $q$ 's utility from choosing alternative  $j$  in choice situation  $t$  in a utility function with random parameters can be defined as

$$U_{jtq} = V_{jtq} + \varepsilon_{jtq} = \beta'_{qk} X_{jtqk} + \delta'_{kzq} Z_{jtqk} + \varepsilon_{jtq} \dots\dots\dots (1)$$

Where respondent  $q$  ( $q=1, \dots, Q$ ) obtains utility  $U$  from choosing alternative  $j$  (Option A, B or C) in each of the choice sets  $t$  ( $t=1, \dots, 6$ ). The utility has a non-random component ( $V$ ) and a stochastic term ( $\varepsilon$ ). The non-random component is assumed to be a function of the vector  $k$  of choice specific attributes:  $X_{jtqk}$ , with corresponding parameters  $\beta_{qk}$  that may vary randomly across respondents due to preference heterogeneity with a mean  $\beta_k$  and standard deviation  $\delta k$ .

The utility function of the model without covariates, except for the error term  $\varepsilon_{jtq}$ , can be expressed as a linear function of an attribute vector  $(X_1, X_2, X_3, X_4, X_5, X_6) =$  (Type of renewable energy, Ownership, Impact on the environment, Distance and Visibility, Job creation, and Proposed yearly tax). It includes the alternative-specific constant representing a dummy for the respondent choosing the status quo option among two alternatives and all the attributes erringly excluded from  $X_{jtqk}$ . It is assumed that the individual chooses the option  $j$  that provides them with the highest utility (Kuu and Yoo, 2010).

$$V_{jq} = ASC_q + \beta_1 X_{1,qj} + \beta_2 X_{2,qj} + \beta_3 X_{3,qj} + \beta_4 X_{4,qj} + \beta_5 X_{5,qj} + \beta_6 X_{6,qj} \dots\dots\dots(2)$$

Research is usually focused on a probability function, defined over an individual's choices with the assumption that the individual will try to maximize their utility (Bergmann et al., 2006). The probability that an individual  $q$  will choose alternative  $i$  over any other alternative  $j$  belonging to some choice set  $t$  of:

$$Prob_{iq} = Prob (V_{iq} + \varepsilon_{iq} > V_{jq} + \varepsilon_{jq}) \quad \forall j \in t$$

Which equals to

$$= Prob \{(V_{in} - V_{jn}) > (E_{jn} - E_{in})\} \dots\dots\dots(3)$$

To estimate observable parameters of the utility function (3), assumptions are made about the random component of the model. First assumption is that the stochastic components are independently and identically distributed (IID) with a Gumbell/Weibull distribution. This results in the use of MNL models to determine the probabilities of choosing  $i$  over  $j$  options.

$$Probin = \exp(\mu V_{iq}) / \sum_j \exp(\mu V_{jq}) \quad \forall j \in t \dots\dots\dots(4)$$

Where  $\mu$  is a scale parameter, inversely related to the standard deviation of the error terms, and

$V_{iq}$  is the deterministic component of the utility function assumed to be linear in parameters:

$$V_{jq} = \sum_k \beta_{jk} X_{jk} \dots\dots\dots(5)$$

Where  $X_{jk}$  is the  $k^{th}$  attribute value of the alternative  $j$  and  $\beta_{jk}$  is the coefficient associated with the  $k^{th}$  attribute. The implications for this are that the estimated  $\beta$  values cannot be directly interpreted, since they are confounded with the scale parameter. However, the marginal rate of substitution (MRS) between any pair of attributes is obtainable:

$$MRS = -(\mu \cdot \beta_{attribute a} / \mu \cdot \beta_{attribute b}) = -(\beta_{attribute a} / \beta_{attribute b}) \dots\dots\dots(6)$$

When the cost is included as an attribute, the equation (6) can be used to produce an estimate of the “implicit price”  $P^*_a$  by replacing the denominator with the  $\beta$  estimate for the cost/price attribute:

$$P^*_a = -(\beta_a/\beta_{cost}) \dots\dots\dots (7)$$

The implicit prices express the marginal WTP for a discrete change in an attribute level.

Similarly, the RPL framework allows for variation across individuals. By introducing individual characteristics,  $Z_q$ , sources of preference heterogeneity can be identified. These variables are interacted with the choice-varying attributes  $Z_{jtqk}$ . This will identify variation in preference associated with individual specific characteristics (Bergmann et al., 2006).

### 5.2.2 Attributes and optimal choice profiles

We considered the current Kenyan energy policy framework in the development of our attributes. The main criteria we considered when selecting the attributes and their corresponding levels include relevance, credibility, and applicability to policy analysis. By using pre-tests, national energy policy documents and existing literature from studies (Bergmann et al., 2006; Ku and Yoo, 2010; Okeefe, 2014) the attributes were selected to characterize renewable energy projects. In this choice experiment, respondents traded-off six attributes described in table 5.1. Type of renewable energy project (TOR) attribute explored the different options of renewable energy that Kenya is considering, including Solar, Wind, Geothermal, and Biomass (KNEP, 2018). The social attributes selected were Type of ownership (OWN) and Distance and Visibility (D&V). The D&V attribute was derived from literature (Bergmann et al., 2006) where the public may have views on visual impact of large projects; hence an attribute to measure the NIMBY (Not In My Backyard) effect following a similar approach by Vecchiato and Tempesta (2015). In the case of OWN attribute, the levels were classified as public (government owned

and community owned project) and private (company, corporation or individual owned). For environmental impact attributes (IOE), we considered impacts such as low, medium, and high and non-specific impacts such state of local biodiversity, carbon emissions or local climate changes. The economic attributes considered were community job creation (CJC) and annual household energy tax (COST) that hypothetically covers the capital costs of the renewable energy projects.

**Table 5.1. Attributes and levels in the choice tasks**

	<b>Description</b>	<b>Levels</b>
Types of Renewable energy source (TOR)	The type of energy source responsible for energy generation	Level 1: Solar (Sol) Level 2: Wind (Win) Level 3: Geothermal (Geo) Level 4: Biomass (Bio)
Ownership (OWN)	Defined as public (government and community owned) and Private (individually, institution or company owned).	Level 1: Public (Pub) Level 2: Private (Pri)
Impact on the environment (IOE)	Impacts on the environment, in-terms of air pollution, effect on wildlife, destruction of ecosystems and deforestation.	Level 1: Low (Low) Level 2: Medium (Med) Level 3: High (Hig)
Distance and Visibility (D&V)	The distance and visibility of the project to your home.	Level 1: Less than 10 Km and Visible (<10Km&V) Level 2: Less than 10 Km and Not Visible (<10Km&NV) Level 3: More than 20 Km and Not Visible (>20Km&NV)
Community job creation (CJC)	New Creation of employment	Level 1: Less than 10 Jobs (<10Jobs) Level 2: Between 10 to 20 Jobs (10-20Jobs) Level 3: More than 20 Jobs (>20Jobs)
Yearly tax on Renewable energy project (COST).	Proposed yearly tax on renewable energy projects.	Level 1: Ksh 300 Level 2: Ksh 600 Level 3: Ksh 900



The associated levels resulted in 648 possible profiles ( $4 \times 2 \times 3 \times 3 \times 3 \times 3$ ) which is an unfeasible number to use in the survey. A D-efficient design was applied to give an efficient combination for orthogonality, level balance, and minimum overlap using the software R. We used a fractional factorial design to reduce the full factorial to 72 choice set profiles that were randomly paired to form 36 choice cards representing two renewable project alternatives and an additional fixed alternative that was described as “no new renewable projects”, equivalent to the status quo alternative (Table 5.2). Based on this design, 36 different choice sets were divided into six blocks of six choice tasks.

**Table 5.2:** Sample choice card including 2 options for renewable energy projects and an opt out.

Attribute	Option A	Option B	Option C
Type of Renewable Energy	Biomass	Wind	No Renewable Energy Project
Ownership	Public owned	Private owned	
Impact on the environment	Low	High	
Distance and Visibility	10 to 20 Km & Not Visible	Less than 10 Km & Not Visible.	
Community job creation	Less than 10 Jobs	10 to 20 Jobs	
Proposed yearly tax on Renewable energy development.	Ksh 900/year	Ksh 300/year	
Your choice (tick only one)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Note:** 100 Kenya shillings (Ksh) = 1 US \$ (2019).

### 5.2.3 Questionnaire and Sampling Framework

The questionnaire consisted of three sections. The first section contained a brief introduction to the survey and background information on renewable energy, the environment, and government policy towards increasing renewable energy. In the second part, the respondents participated in a choice experiment, in which they were asked to choose between two different renewable energy development scenarios, and the status quo as described in Table 5.1. The last

section contained socioeconomic information about the respondent (gender, age, education, residence, occupation, household income, and access to electricity). The sampling framework is described in section 4.2.1 of chapter 4 with respect to the Kenyan respondents.

#### **5.2.4 Model Estimation**

To analyze the results, we applied MNL and RPL to evaluate preference heterogeneity, which has been described in the research by Ek and Pearson (2014). We applied interaction factors such as age, residence and education, which may further explain the probability of selecting specific attributes for renewable energy projects. The econometric analysis for the parameter and willingness to pay estimates was conducted with the software STATA 15, which applies both the MNL and RPL framework with 200 Halton draws to give the mean and standard deviation for preference heterogeneity.

### **5.3. Results and Discussion**

#### **5.3.1 Descriptive Statistics.**

The descriptive statistics show that the sample and population have a goodness of fit for most of the socio-demographic factors. At a 1% significance level, the evidence for rejection of the null hypotheses of the equality of means was found for annual household income, percentage rural population, and percentage electricity access for rural population. The descriptive statistic is previously described in section 4.3.1. of chapter four that illustrates the socio-demographic characteristics of the survey area for Kenya (Table 4.2)

#### **5.3.2 Estimation results**

The estimated coefficients derived from the MNL and RPL and their corresponding interaction effects are shown in Table 4.3. Although both models attribute level coefficients were consistent in terms of magnitude, signs and level of significance, some attribute levels had some

expected and unexpected signs. The goodness-of-fit of the RPL model ( $\text{pseudo-R}^2 = 0.0322$ ) was not as high as the equivalent MNL model with a  $\text{pseudo-R}^2 = 0.4238$ . However, the log likelihood value of function of the RPL model was much higher than the MNL model, indicating that the RPL is random and provides better estimates than MNL. As expected from economic theory, the cost coefficient of both models is negative and statistically significant. Other than both CJC attributes levels, all coefficient standard deviations in the RPL are significant, an indication that respondent preferences are heterogeneous. Heterogeneity could be attributed to differences in perceptions or views held by respondents about the potential impacts and benefits from renewable energy projects. It is apparent that there is no segment of the population that have an alternate view about renewable energy's providing jobs. In-order to avoid a saturated model, one attribute level for each of the attributes was chosen as the baseline or reference case.

**Table 5.3:** Parameter estimates standard errors within parenthesis.

Attribute levels and interactions	MNL	RPL	
	Estimate	Mean	Std Dev
TOR (Sol)	0.913(0.054) ***	1.761(0.141) ***	1.605(0.184) ***
TOR (Win)	0.513(0.051) ***	0.771(0.106) ***	1.077(0.183) ***
TOR (Bio)	0.347(0.052) ***	0.411(0.100) ***	-1.279(0.186) ***
OWN (Pub)	0.234(0.055) ***	0.428(0.138) **	1.742(0.165) ***
IOE (Low)	1.624(0.062) ***	3.581(0.253) ***	2.787(0.252) ***
IOE (Med)	0.953(0.064) ***	1.994(0.173) ***	1.126(0.187) ***
D&V (< 10 Km & NV)	0.451(0.076) ***	0.804(0.172) ***	-1.031(0.187) ***
D&V (10-20 Km & NV)	0.392(0.071) ***	0.562(0.159) ***	1.294(0.178) ***
CJC (10-20Jobs)	0.377(0.078) ***	0.870(0.188) ***	-0.283(0.200)
CJC (> 20Jobs)	0.182(0.082)	0.641(0.189) ***	-0.429(0.351)
COST	-0.001 (0.001) ***	-0.001(0.001) ***	0.001(0.001) ***
ASC	49.980(7.75) ***	40.655(6.826)	-4.839(0.237)
Interactions			
Age * (10-20 Jobs)	0.192(0.091)	0.347(0.210)	-0.154(0.259)
Age * (> 20Jobs)	0.221(0.092)	0.661(0.221) **	1.303(0.225) ***
Residence * Public	0.210(0.065) ***	0.349(0.176)	1.118(0.214) ***
Education * (< 10 Km & V)	0.701(0.079) ***	1.053(0.181) ***	0.959(0.196) ***
Education * (<10 km & NV)	0.442(0.088) ***	-0.770(0.209) ***	0.866(0.272) ***
Pseudo R <sup>2</sup>	0.4282	0.0365	
Wald chi <sup>2</sup> (17)	5757.67	683.58	
Prob> Chi <sup>2</sup>	0.000	0.000	
Loglikelihood	-3844.674	-3502.88	
Number of Respondents	1020		
Number of Observations	6120		

**Note:** \*\*\*, \*\*, and \* indicate statistical significance at the 1%, 5% and 10% levels, respectively. Values in parentheses show standard errors.

#### a. Main Effects

In both the MNL and RPL models, all the renewable energy technologies (solar, wind and biomass) were statistically significant and exhibited positive utility to the respondents, suggesting significant support for all renewables by the public. Consistent with the MNL and RPL models, preference heterogeneity (given by standard deviation) in the RPL model was

significant at all levels and largest for solar, followed by wind and biomass. This result is similar to the findings from Yoo and Ready, 2014. The coefficient for public ownership (Pub) in both models was statistically significant. The standard deviation in the RPL model is also statistically significant, indicating preference heterogeneity among the respondents. This finding is consistent with studies by Ek and Pearson (2014), who found preference towards public owned (municipality and cooperatives) over private owned wind farms. This was a counterintuitive outcome for our study, as introduction of privately-owned renewable projects to meet energy demands should be supported by the public.

All impact on environment (IOE) attributes have positive coefficients and are statistically significant in MNL and the RPL model. This indicated that there is considerable preference heterogeneity for renewable energy projects with low and medium impact on the environment. These results are similar to findings in studies by Bergmann et al., (2008) that considered attributes such as impact on air pollution and wildlife. The D&V attributes has similar results in both the MNL and RPL models, and the coefficients at both levels are positive and statistically significant. The distance and visibility attribute (D&V) a measure of NIMBY, indicating that NIMBYism not yet become a concern. Most respondents accept all types of renewable energy near their homes. Although, all the community job creation (CJC) attributes were positive, there was a mixed outcome as more than 20 jobs level was not significant in the MNL but was significant for the RPL, the standard deviation was not significant, hence no preference

heterogeneity among respondents. For between 10 to 20 jobs level, MNL is statistically significant whereas the RPL model is not significant.

#### b. Interaction Effects

We considered socio-economic variables such as age, residence, and education as interaction effects for different renewable energy project attributes. Age was interacted with the community job creation attribute, education was interacted with distance and visibility, and residence was interacted with ownership. The interaction effects for age and community job creation were not statistically significant. On the other hand, the interaction effect for residence and public ownership was significant in the MNL but not significant in the RPL, this means that rural residents had negative attitudes towards private ownership in the MNL model. Our findings are in line with studies by Bergman et al., 2008, Kosensius and Ollikainen (2013), and Warren and McFadyen, 2008 who found that rural residents have greater support for public rather than privately owned renewable energy projects. Given that 73% of the population in Kenya resides in rural areas, of which only 23% have access to electricity (KNEP, 2018), there is a need by the government to shift the negative view of private ventures among rural residents for the successful deployment of privately owned renewables. Although unexpected, education and distance interaction terms are significant in both the MNL and RPL models indicating preference heterogeneity.

#### **5.3.3 Willingness to Pay**

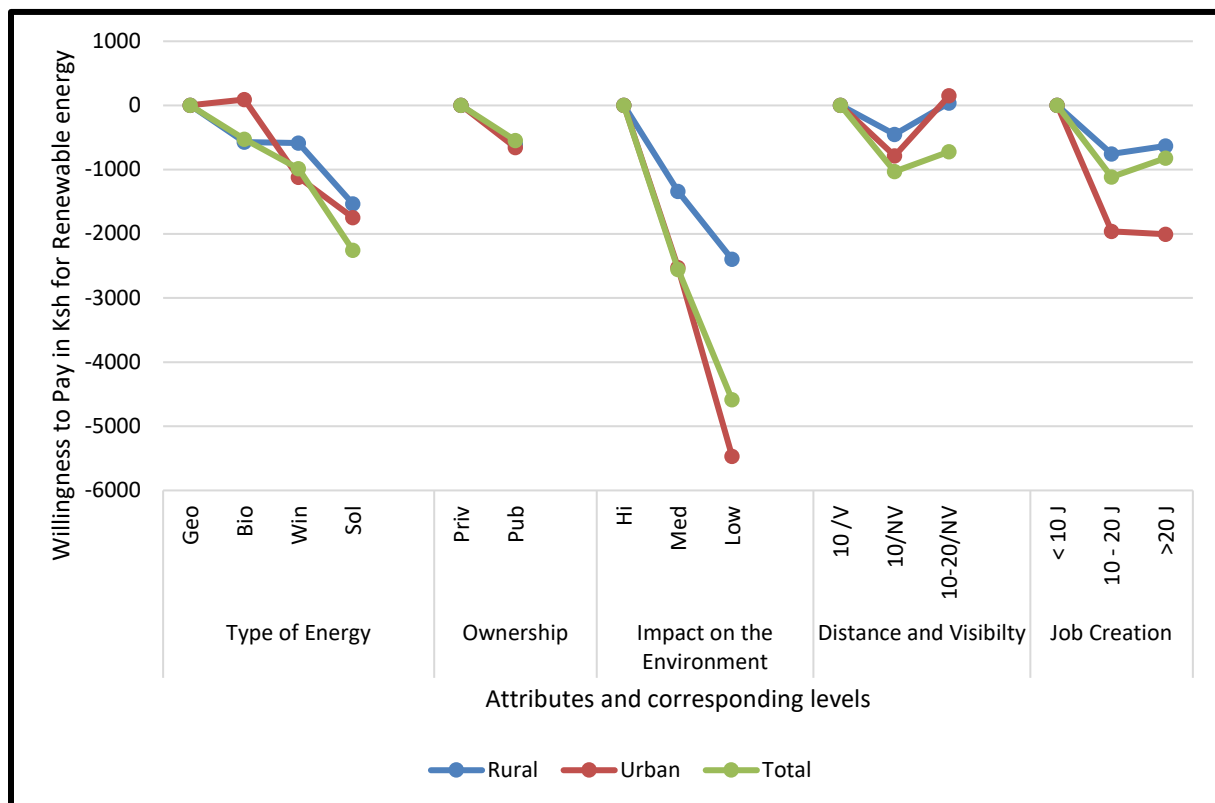
The marginal WTP measures are presented in Figure 5.1. In general, the IOE attribute seems to have a relatively large impact on the utility, followed by the TOR, CJC, D&V, and OWN, respectively, for both rural and urban respondents. For the TOR attribute, the highest willingness to pay was for solar energy, followed by wind energy and biomass energy. Solar

energy is the most preferred energy source for both urban and rural residents, with urban residents showing a greater preference for solar energy. Rural residents are willing to pay Ksh 1,535.96 for solar energy, whereas urban residents are willing to pay Ksh 1,749.68. This relatively high preference for both urban and rural residents could be attributed to the prevalence of small off-grid solar panels provided by incentivized programs offering solar panels on loans that are payable through mobile phone programs, making solar in Kenya very successful (KNEP, 2018). For other types of energy there are mixed outcomes, with urban residents expressing a higher willingness to pay for wind energy (Ksh 1,121.27) as compared to rural residents (Ksh 584.84). Whereas, the rural resident's willingness to pay for biomass was higher (Ksh 572.33), and urban residents expressed a positive WTP sign of Ksh 94.41. The positive WTP sign can be interpreted as the respondent preference to be compensated in-order for the attribute level to be acceptable.

Overall, compared with other renewable energy sources, biomass had the lowest willingness to pay value, indicating a relatively low preference. This was an expected outcome, as investments in biomass technologies has yet to reach a viable and sustainable level for electricity production. Negative views of biomass may also come from woodfuel, mainly used as a cooking fuel in both rural and urban households, and their unsustainable use have resulted in a negative impact on the environment (Mohammed et al., 2013). Bergmann et al 2006 and O'Keefe (2014), support the view that the type of energy source is significant in determining the likelihood that the individual will choose one project over the other. In most cases, an individual's willingness to pay is determined by their knowledge and presence of the technologies. Closer analysis on the D&V attribute reveals that urban residents are willing to pay Ksh 440.68 more to have renewable energy projects that are between 10 to 20 Km and not

visible to their homes, as compared to projects that are less than 10 km and not visible from their homes. This could be attributed to the fact that most renewable energy projects are often situated in rural areas, where the residents must bear the negative externalities that these projects (Bergmann et al., 2006).

For the IOE attribute, urban residents still have a greater willingness to pay for the low impact on the environment. Similarly, for the CJC attribute, the urban residents had a greater willingness to pay for job creation from renewable energy projects. Studies by Ek and Pearson (2014) and Warren and McFadyen (2014) indicate citizen support for community owned renewable projects, this finding is similar to our study that show respondents supporting publicly owned as opposed to privately owned renewable energy projects.



**Figure 5.1:** Willingness to pay for renewable energy attributes



### 5.3.4 Policy simulation.

From the estimated coefficients of the attributes, it is possible to estimate the mean WTP for various scenarios with different combinations of attributes, wherein tradeoffs can be established to give information on the benefits of realistic policy scenarios. In this chapter, we analyze our policy scenario with an actual government policy target for the year 2020 of 2700MW for new renewable energy projects (Power Africa, 2018). Through this scenario analysis on solar, wind and biomass projects with the optimal attribute levels used in the study, we work out the percentage of government targets that citizens are willing to pay. This was achieved by multiplying the annual mean WTP by the total number of households in Kenya. According to Kenya Integrated Household Budget Survey (KIHBS), there were 11,840,985 households in Kenya as of 2016. The total willingness to pay for the three scenarios is presented in Table 5.4 below. We assume that the policy target year will be extended to 2024 to analyze the implementation effect of the policy after four years. The second assumption is to adjust the capacity of 2700MW to 3100.33 MW to account for increasing energy demand at 3.6% per year for four years (Power Africa, 2018). We derived the capital costs from (International renewable energy agency (IRENA) using the median estimate of installed capacity of all the renewables. The capital costs did not include the variable operation and management costs (IRENA, 2018).

The policy simulation suggests that while renewable energy adoption is significantly valued by households, forming 49.614% of the total Kenyan energy government target. Although the contribution from consumer willingness to pay is significant, it is still not enough to cover for

the higher capital cost for the development of the technology. Consequently, the government needs to institute additional measures to meet the deficit (Table 5.4).

**Table 5.4:** Scenarios for renewable energy investment

	<b>Solar</b>	<b>Wind</b>	<b>Biomass</b>
WTP/HH/year	\$ 220.90	\$ 188.78	\$ 183.34
Total WTP of Kenyan HH	\$ 1.593 Billion	\$ 0.596 Billion	\$ 0.308 Billion
Total MW	612.54 MW	313.62 MW	616.98 MW

**Note:** The WTP in the scenario analysis is estimated in US \$ (Where 1 US \$ = 100 Ksh).

WTP: Willingness to Pay

HH: Household

MW: Megawatt

## 5.4 Conclusion and Policy implications

Renewable energy development in Kenya presents a solution to addressing climate change while simultaneously providing energy access and building the economy through providing jobs. The Kenyan government has mandated that 83% of the primary energy supply should be from renewable energy sources by 2020. This ambitious target can be achieved mainly through sound policies and efficient implementation. The goal of this chapter was to address the need for more quantitative information to assist policymakers take necessary measures by considering the socio-economic and environmental cost of potential renewable energy projects. Designing policy instruments requires inputs that consider lowest possible adverse socio-economic and environmental impacts for a given quantity of power output for a more sustainable future.

Overall, this study estimated the values of renewable energy development using the choice experiment as an economic valuation to estimate trade-off between goods, allowing for respondent preferences and policy scenarios to be evaluated. This was geared towards providing

important information for Kenyan energy policy by eliciting citizens' preferences for various attributes of renewable energy (Solar, Wind, Biomass, and Geothermal). We established that respondents a higher preference for solar, followed by wind, biomass, and geothermal respectively. The results also reveal that the Kenyan public places a high value on environmental impact and job creation, and lower value on ownership and distance and visibility. Regional differences in preferences for renewable energy indicate stronger support for renewable energy development and its attributes among urban residents as compared to the rural residents. Sustainable measures include diversifying the economy by tapping into different types of renewable energy depending on the socio-economic attributes and potential of the project sites. Diversification should be based on the development of a sound system that support residents through incentives for small scale renewables.

## **6. Public preferences for Renewable Energy options: A choice experiment in Rwanda**

### **6.1 Introduction.**

In Chapter 6, we examined the marginal valuation of economic, social, and environmental impacts of renewable energy sources (small-hydro, solar, biomass and geothermal) using the choice experiment method in Rwanda. Unlike chapter 4 that uses a comparative approach of the level of acceptance, awareness, and attitudes towards renewable energy for both countries, chapter 5 and 6 consider the two countries as stand-alone case studies without comparative analysis; this is done primarily because their renewable energy portfolios differ in the choice experiment section, with Kenya having wind as one of the alternatives and Rwanda replacing wind with small-hydro. It was necessary to make this adjustment, as Rwanda is a country with unsuitable terrain for wind energy. We consider small hydro instead of big dams, as the focus of renewables has shifted from mega hydropower projects that have impacted the environment. We also investigated how socio-demographic characteristics of the respondents (rural/urban residence, age groups, and education) among respondents affect their willingness to pay for certain attributes of renewable energy development.

Currently, in Rwanda there is no information available on the public preferences for characteristics of renewable energy production alternatives. The chapter aims to fill this gap by focusing on key attributes of renewable energy development that are critical in shaping up suitable policy. This is facilitated by considering attributes such as ownership and community job creation that are unique to the SSA scenario by allowing for effective trade-offs between the renewable energy attributes. The analysis was carried out using the MNL and RPL framework to allow for possible preference heterogeneity across individuals.

## 6.2 Methods.

### 6.2.1 Theoretical Framework

Theoretical framework will be the same as section 5.2.1 of chapter 5.

### 6.2.2 Attributes and optimal choice profiles

We considered the Rwanda energy policy framework (REP, 2018), pre-tests and existing literature from studies such as Bergmann *et al.*, 2006, O’Keefe, 2014, Ku and Yoo, 2010 and Vecchiato and Tempesta, 2015 in the development of the attributes (Table 6.1).

**Table 6.1:** Attributes and levels in the choice tasks

	Description	Levels
Types of Renewable energy source (TOR)	The type of energy source responsible for energy generation	<ul style="list-style-type: none"> <li>• Solar (Sol)</li> <li>• Small hydro (Hydro)</li> <li>• Geothermal (Geo)</li> <li>• Biomass (Bio)</li> </ul>
Ownership (OWN)	Defined as public (government and community owned) and Private (individually, institution or company owned).	<ul style="list-style-type: none"> <li>• Public (Pub)</li> <li>• Private (Pri)</li> </ul>
Impact on the environment (IOE)	In-terms of air pollution, effect on wildlife, destruction of ecosystems and deforestation.	<ul style="list-style-type: none"> <li>• Low (Low)</li> <li>• Medium (Med)</li> <li>• High (Hig)</li> </ul>
Distance and Visibility (D&V)	The distance and visibility of the project to your home.	<ul style="list-style-type: none"> <li>• Less than 10 Km and Visible (&lt;10Km&amp;V)</li> <li>• Less than 10 Km and Not Visible (&lt;10Km&amp;NV)</li> <li>• More than 20 Km and Not Visible (&gt;20Km&amp;NV)</li> </ul>
Community job creation (CJC)	New Creation of employment	<ul style="list-style-type: none"> <li>• Less than 10 Jobs (&lt;10Jobs)</li> <li>• Between 10 to 20 Jobs (10-20Jobs)</li> <li>• More than 20 Jobs (&gt;20Jobs)</li> </ul>
Yearly tax on Renewable energy project (COST).	Proposed yearly tax on renewable energy projects.	<ul style="list-style-type: none"> <li>• Rwf 3000</li> <li>• Rwf 6000</li> <li>• Rwf 9000</li> </ul>

- Note: 1 US \$ = Ksh 100 = Rwf 1,000 (2019). These are approximate values rounded off.

The associated levels resulted in 648 possible profiles ( $4 \times 2 \times 3 \times 3 \times 3 \times 3$ ) which is an unfeasible number to use the survey. A D-efficient design was applied to give an efficient combination for orthogonality, level balance, and minimum overlap using the software R. We used a fractional factorial design to reduce the full factorial to 72 choice set profiles that were randomly paired to form 36 choice cards representing two renewable project alternatives and an additional fixed alternative that was described as “no new renewable projects”, equivalent to the status quo alternative (Table 6.2). Based on this design, the 36 different choice sets were divided into six blocks of six choice tasks.

**Table 6.2:** Sample choice card including 2 options for renewable energy projects and an opt out.

Attribute	Option A	Option B	Option C
Type of Renewable Energy	Small hydro	Solar	No Renewable Energy Project
Ownership	Public owned	Private owned	
Impact on the environment	Low	High	
Distance and Visibility	10 to 20 Km & Not Visible	Less than 10 Km & Not Visible.	
Community job creation	Less than 10 Jobs	10 to 20 Jobs	
Proposed yearly tax on Renewable energy development.	Rwf 9,000	Rwf 3,000	
Your choice (tick only one)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Note:** 1000 Rwandan Francs (Rwf) = 1 US \$ (2019).

### 6.2.3 Questionnaire and Sampling Framework

The questionnaire and sampling framework is the same as chapter 4, the only difference is the proposed yearly tax section the currency is in Rwf instead of Ksh. Also, for Type of renewable energy attribute type small hydro replaces wind energy in the Rwandan survey.

#### 6.2.4 Model Estimation

For the estimation of the results, we applied the MNL and RPL to evaluate preference heterogeneity as elaborated in studies by Ek and Pearson, 2014. We applied additional interaction factors such as age, residence, and education that may further explain the probability of choosing specific attributes for renewable energy projects. The econometric analysis for the parameter and willingness to pay estimates was conducted with the software STATA 15 that applies the MNL and RPL framework with 50 Halton draws to give the mean and standard deviation for preference heterogeneity.

#### 6.2.5 Estimation results

The coefficients of the utility function for the attribute levels had some expected and unexpected signs for both models indicating a very good fit when comparing the loglikelihood values at zero and at convergence (Table 6.3). The goodness-of-fit of the RPL model (pseudo- $R^2 = 0.0276$ ) was not as high as the equivalent MNL model with a pseudo- $R^2 = 0.5579$ , and the log likelihood value of function of the MNL model was much higher than the RPL model, indicating that the MNL provides better estimates than the RPL. The coefficient was negative and but not statistically significant for both models, indicating that Rwandan respondents, utility decreases as the price for renewable energy project alternatives increases. Most coefficient standard deviations in the RPL are significant, an indication that respondent preferences are indeed heterogeneous. Heterogeneity could be attributed to differences in perceptions or views held by respondents about the potential impacts and benefits from renewable energy projects.

**Table 6.3:** Parameter estimates standard errors within parenthesis

Attribute levels and interactions	MNL	RPL	
	Estimate	Mean	Std Dev
TOR (Sol)	0.453(0.063) ***	0.961(0.119) ***	-0.715(0.190) ***
TOR (Hydro)	0.653(0.067) ***	1.254(0.129) ***	1.231(0.185) ***
TOR (Geo)	0.199(0.063) ***	0.398(0.101) ***	0.427(0.250)
OWN (Pub)	0.341(0.069) ***	0.513(0.138) ***	1.150(0.137) ***
IOE (Low)	3.192(0.083) ***	6.149(0.357) ***	3.004(0.235) ***
IOE (Med)	1.878(0.083) ***	2.944(0.195) ***	0.215(0.284)
D&V (< 10 Km & V)	0.441(0.096) ***	0.608(0.173) ***	-1.171(0.171) ***
D&V (< 10 Km & NV)	0.682(0.095) ***	1.198(0.184) ***	-0.008(0.750)
CJC (10-20 Jobs)	0.371(0.079) ***	0.743(0.159) ***	-0.050(0.212)
CJC (>20Jobs)	0.162(0.084) ***	0.646(0.158) ***	0.261(0.315)
COST	-0.001(0.001)	-0.001(0.001)	0.001(0.00') ***
ASC	45.666(5.740)	33.614(6.967)	-0.812(5.616)
<b>Interactions</b>			
Age * (10-20 Jobs)	0.270(0.102) *	0.488(0.196)	-0.029(0.267)
Age* (>20 Jobs)	0.226(0.100)	0.368(0.199)	1.328(0.238) ***
Residence * Public	-0.0148(0.080)	0.032(0.162)	0.419(0.255)
Education * (< 10 Km & V)	0.460(0.109) ***	0.764(0.198) ***	-0.523(0.314)
Education * (<10 km & NV)	0.257(0.108)	0.345(0.207)	1.081(0.287) ***
Pseudo R <sup>2</sup>	0.5636	0.0276	
Wald chi <sup>2</sup> (17)	7461.28	606.58	
Prob> Chi <sup>2</sup>	0.000	0.000	
Loglikelihood	-2888.49	-2585.21	
Number of Respondents		1006	
Number of Observations		6,036	

**Note:** \*\*\*, \*\*, and \* indicate statistical significance at the 1%, 5% and 10% levels, respectively. Values in parentheses show standard errors.

All the renewable energy technology's coefficients (small-hydro, solar and geothermal) are statistically significant and had positive signs in both the MNL and RPL models. The results show that the public provide strong support for all renewable energy types. The standard deviation in the RPL model for solar and small-hydro are significant with a lower magnitude for their respective means, indicating preference heterogeneity for the energy sources. This



heterogeneity can be attributed to power intermittency, which are caused by irregular seasonal patterns that make small hydropower unreliable in Rwanda (Geoffrey et al., 2018). In the case of solar the negative magnitude in the standard deviation can be attributed to, the poor quality of solar panels in the off-grid market (REP, 2018) (Table 6.3). In both models the public ownership coefficient was positive and statistically significant, indicating support for publicly owned renewable energy projects.

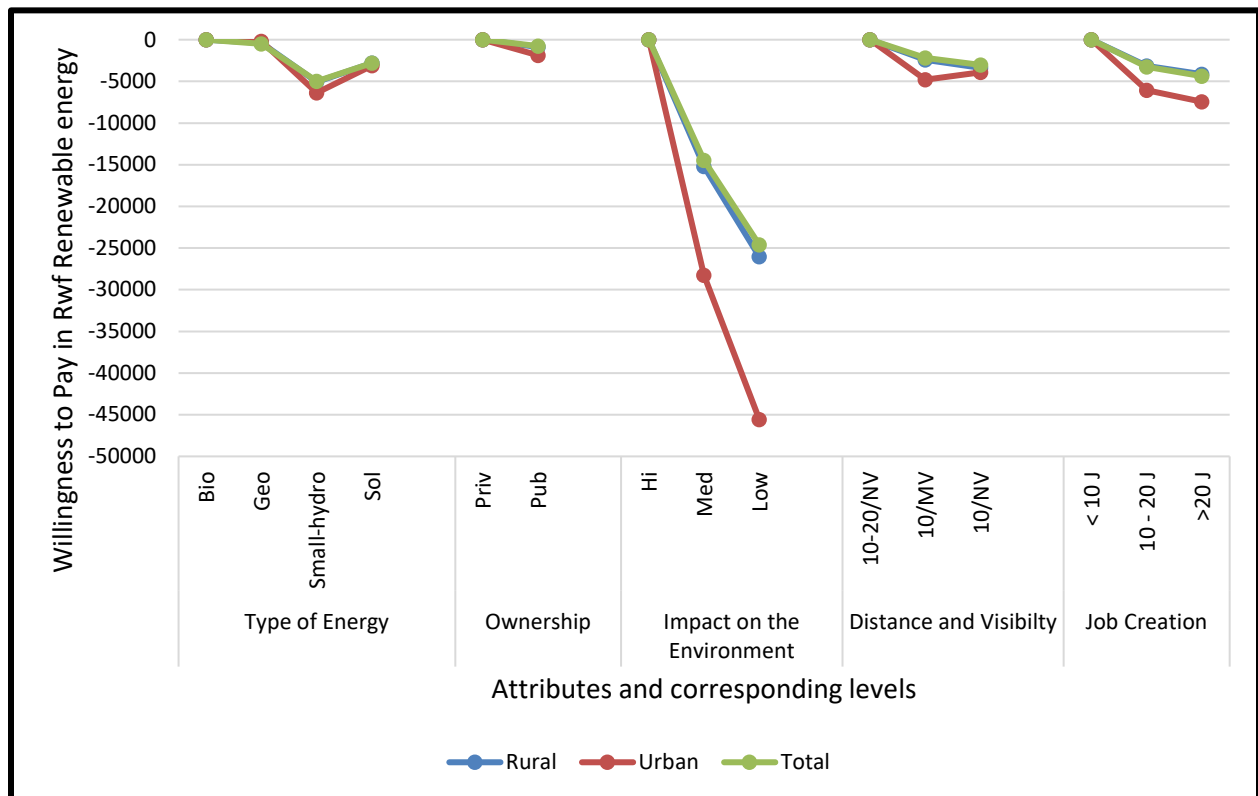
All impact on environment (IOE) attributes had positive coefficients and are statistically significant in MNL and the mean for RPL model. However, only the low attribute level in the RRL has a standard deviation that was significant, indicating considerable heterogeneity in preference for renewable energy projects with low impact on the environment. The D&V attributes has similar outcomes in both the MNL and the mean for RPL models, with both levels having a positive coefficient and being statistically significant. However, only the standard deviation for the attribute level ( $< 10$  Km & V) has a standard deviation that is statistically significant. On the other hand, all the community job creation (CJC) attributes are positive and significant for both models, but for the RPL there was no preference heterogeneity. We considered socio-economic variables such as age, residence, and education as interaction effects for different renewable energy project attributes. Age was interacted with jobs, education was interacted with distance and visibility and residence was interacted with ownership. Overall, the interaction terms are not statistically significant except for education and ( $< 10$  Km & V) for both MNL and RPL model

### 6.2.6 Willingness to Pay

The marginal WTP measures for Rwanda are presented in Figure 6.2. The IOE attribute seems to have a relatively large impact on the utility, followed by the TOR, CJC, D&V, and OWN, respectively for both rural and urban respondents. For the TOR attribute, the highest willingness to pay was for small hydro followed by Solar and Geothermal. Small hydro energy is the most preferred energy source for both urban and rural resident, with urban residents showing a greater appeal for small-hydro power. Respondents are willing to pay Rwf 5,071.32 for small hydro in rural areas and Rwf 6,386.29 in urban areas. For other types of energy, both urban and rural residents express a higher willingness to pay for solar (Rwf 2,800.33) while expressing lower willingness to pay for geothermal (Rwf 492.98). This was an expected outcome, as Rwanda is still at the exploratory phase for Geothermal energy (Uwisengeyimana, 2016). Closer inference on the D&V attribute further reveals that urban residents have a higher willingness to pay for renewable energy projects that are less than 10 Km and not visible (Rwf 3,895.13) as compared to rural residents (Rwf 3,388.04). Furthermore, urban residents' willingness to pay for renewable energy projects that are less than 10 Km and visible to their residences is Rwf 4,795.37 while for rural resident's projects that are less than 10 Km and not visible is (Rwf 2,420.71). This can be interpreted as the Rwandan population is willing to pay more to have renewable energy projects closer to their homes. From the perspective of the NIMBY debate, this result should be an unexpected outcome. For Rwandan policy makers, it is an indicator that there is minimum objection to bringing renewable energy projects close to the public residences.

For the IOE attribute, the expected results are that, given the higher income and education level of urban residents, should translate to a greater willingness to pay for impact on the environment. This was in line with our findings, as urban residents have a greater willingness to

pay for the low impact on the environment. Similarly, for CJC attribute, the urban residents had a greater willingness to pay for job creation from renewable energy projects. Residents in the urban areas have a greater willingness to pay for publicly owned renewable energy projects (Rwf 1,860.76) as compared to rural residents (Rwf 893.42).



**Figure 6.1:** Willingness to pay for renewable energy attributes.

### 6.2.7 Policy simulation.

From the estimated coefficients of the attributes, it is possible to estimate the mean WTP for various scenarios with different combinations of attributes, wherein tradeoffs can be established to give information on the benefits of realistic policy scenarios. In this chapter, we analyze our policy scenario with an actual government policy target for the year 2024 of 296 MW for new renewable energy projects in Rwanda (REG, 2018). Through this policy simulation exercise on solar, small-hydro and geothermal and biomass projects with the optimal attribute

levels used in the study, we work out the percentage of government targets that citizens are willing to pay for. This was achieved by multiplying the annual mean WTP by the total number of households in Rwanda. According to National Institute of Statistics (NISR), there were 3,012,143.72 households in Rwanda as of 2018. The total willingness to pay for the three scenarios is presented in Table 6.4 below. We derived the capital costs from (International renewable energy agency (IRENA) using the median estimate of installed capacity of all the renewables. The capital costs did not include the variable operational and management costs (IRENA, 2018). The policy simulation suggests that renewable energy adoption is significantly valued by households, forming 145.778% of the total Rwandan energy government target, the value, indicates that there is overwhelming support, that can be converted to fiscal support to meet the Rwandan energy deficit. (Table 5.4).

**Table 6.4:** Scenarios for renewable energy investment.

	<b>Small-hydro</b>	<b>Solar</b>	<b>Geothermal</b>
WTP/HH/year	\$ 160.85	\$ 158.61	\$ 156.11
Total WTP of Rwandan HH	\$ 930.085 Million	\$ 702.839 Million	\$ 286.490 Million
Total MW	903.87 MW	270.32 MW	103.054 MW

**Note:** The WTP in the scenario analysis is estimated in US \$ (Where 1 US \$ = 1000 Rwf).

WTP: Willingness to Pay

HH: Household

MW: Megawatt

### 6.3 Conclusion and Policy implications

Chapter 6 uses choice experiments as an economic assessment method to estimate the impact value of renewable energy development, to assess trade-off between non-market commodities, and to allow assessment of respondents' preferences. This was geared towards providing important information for Rwandan energy policy by eliciting citizens preferences for attributes of renewable energy (solar, biomass, small hydro and geothermal). We determined that respondents have a higher preference for small hydro, followed by solar, biomass and geothermal respectively. The results are similar to Chapter 5, wherein the Kenyan respondents placed a high utility on the impact on the environment and job creation, and a lower value for ownership and distance and visibility. Regional differences in preferences for renewable energy indicate strong support for renewable energy development and its attributes among the rural residents as compared to the urban residents. Rural populations provide the building blocks in terms of economies of scale that are vital for economy economic growth. Sustainable measures include diversifying the economy by tapping into different types of renewable energy depending on the various socio, economic, and potential of the project sites. The basis of diversification should be providing financial incentives for off-grid/minigrids.

This chapter is unique in the sense that it will inform policy measures that can be undertaken to increase support for renewable energy development by the public. The study will open the gateway to similar studies in SSA that are critical for maintaining and strengthening the momentum for the renewable energy development in the region. The role of the government is to show political will by ensuring focus is on strong long-term policies to ensure that the sector flourishes.

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## **7. Conclusions, limitations, and future work**

Chapter 2 examined emerging trends in renewable energy research in peer-reviewed publications with the goal of identifying research gaps, research perspectives, current knowledge, and development of research over time to further assist in developing the theme of subsequent chapters and serve as a literature review. We illustrated that the topic of renewable energy has attracted a growing number of research perspectives in SSA. Temporal analysis confirms that the scientific publications in the field of renewable energy have experienced substantial growth during the period between 1990 and 2016, with biomass energy publications being the most dominant renewable energy type studied in SSA. The network and density visualization of publication's abstracts revealed that most of the terms pertained to biomass-related topics. A noteworthy insight was the fact that there has been a shift of the discussion from the traditional sources of biomass (woodfuel and charcoal) to more efficient biomass options such as bio-fuel crops.

Chapter 3 considers a specification and scenario analysis, in which we find significant and substantive influence of renewable energy consumption on social, economic and environmental factors. In other words, renewable energy consumption plays a vital role in increasing total labor force, forest area, and life expectancy while subsequently it reduces income, carbon emissions, cost of living, and education indexes. Investment in renewable energy goes hand in hand with development of reliable grid systems (local and regional). This will serve to increase economies of scale, necessary for supporting the viability of these capital-intensive projects, stimulating economy and boosting income. In-order for these goals to be realized, there is a need for policies to establish realistic targets that stipulate mandates for required percentage of energy from renewable sources. There is a need to establish a strong link between economic

growth and renewable energy consumption, as an increase in income may result in a switch towards renewable sources of energy. SSA countries should invest more on renewable energy sources in-order to promote economic growth that is sustainable and environmentally friendly to reduce carbon emissions. Due to the vast distribution of renewable potential in SSA, policy should be tailored to be specific for effective outcomes for renewable energy development. Particularly, policies should provide economic incentives and subsidies that are geared towards making renewable energy cost more competitive with traditional fossil fuels. SSA governments should move with urgency to remove bottlenecks that curtail integration of renewable energy into the national grid by waiving taxes for renewable energy projects in regions that have great resource potential to encourage renewable energy investments.

The electricity sectors of Rwanda and Kenya showcase the milestones and challenges encountered by many SSA countries as they strive to establish green and inclusive economies. As Rwanda and Kenya seek to increase their renewable energy portfolio, there is a need to consider public participation. To this goal, Chapter 3 covered a comparative analysis of two nationwide surveys to investigate Rwandan and Kenyan acceptance, awareness, and attitudes towards renewable energy. The findings for this chapter support the view that public opinion, especially on matters regarding the development of renewable energy, are closely monitored by the public. Chapter 3 reveals that there is an overwhelming support towards all renewables. In summary, there needs to be a shift from traditional approaches that focus on ensuring that energy demands are met without considering the energy consumer. Investigating awareness, acceptance and attitudes of the public concerning aspects of renewable energy is critical for providing insightful information that will be important for effective policy formulation.

Chapter 4, has revealed that there is overwhelming support towards all renewables in both countries, with some small socio-demographic segments of the population having neutral or negative attitudes towards renewables. As a result, policy initiatives should be rechanneled to the next step that should focus on integrating both public participation and private partnerships through innovative market technologies (off-grids and mini-grids) that will simultaneously provide energy access and new sources of income. As renewable energy deployment takes a foothold in many communities the next step of engaging the public will be to require their input in the process of assessing the overall benefits of different attributes of renewable energy technologies such as impacts on the environment, job creation, distance and visibility and ownership.

Chapter 5 and 6 estimated the values of impacts of renewable energy development using the choice experiment as an economic valuation to estimate trade-off between goods and allowing for respondent preferences and policy alternatives to be evaluated. This was geared towards providing important information for Kenyan and Rwandan energy policy by eliciting citizen preferences for attributes of renewable energy (solar, wind, biomass, small hydro, and geothermal). We determined respondents in Kenya and Rwanda have a high WTP for renewable energy. The results also reveal that both the Kenyan and Rwandan public place a high value on the impact on the environment and job creation and a lower value on ownership and distance and visibility. Regional differences in preferences for renewable energy indicate stronger support for renewable energy development and its attributes among the rural residents as compared to the urban residents.

Based on our findings, the key talking points for decision-makers/policy makers to consider in designing future renewable energy options for sub-Saharan Africa are:

- Information about regional preferences is critical to for negotiating trade-offs (renewable energy benefits & burdens) in the communities that these renewables will be deployed.
- Diversification of renewables is necessary and should be based on public preferences, socio-economic attributes and geographical potential.
- There is a need for public-private partnerships, to ease the public negative perception on privately owned institutions
- There is a need to increase programs for technical, research, and financial assistance (e.g. forming cooperatives for small loans for community solar) that support small/mini-grid renewables in remote areas to create new economic hubs.
- Publicity campaigns on renewable energy should disseminate information through appropriate media. For example, people in rural areas use radio as a means of obtaining information.
- Data-driven policy simulations show that each case study has unique factors that determine the optimal energy mix, which is critical for designing regional policies.

Overall, this thesis investigated future renewable energy options for SSA, by using various econometric approaches to probe into the various issues that impact renewable energy development. In summary, there is overwhelming evidence of public support for renewables in our case-studies. The next step would be extending the case-studies to other SSA countries, and tasking decision makers to integrate public input in formulation and implementation of effective policies in-order to realize green and prosperous economies for SSA.

## **Limitations and Future studies**

In chapter 2 the study limitations result from the use of bibliometric techniques, which captures abstract, keywords and titles, while text mining covers the entire article, which can reveal more spatiotemporal trends. From a technical point of view, the VOSviewer software used in this study was more compatible with the txt file information drawn from Scopus and Web- of- science. Even so, it is a bold approach to use VOSviewer for a database traditionally not designed for bibliographic mapping, as it marks the first step in addressing the incompatibility issues that have arisen and have been highlighted in this study for future scenarios.

In Chapter 3, the random and fixed effects panel data approach to estimating models has its statistical strengths and weakness, with major concerns relating to endogeneity and serial correlations. Since the employment opportunities created by renewable energy projects affect the economy, this connection may imply that the model has a certain degree of endogeneity. We conducted tests for endogeneity using the 2SLS and use the instrumental variable approach to detect valid instruments against the endogenous variables. For future consideration, other endogeneity model estimation techniques such as GMM should be considered. Interpretation of the findings required caution, as any econometric model may not be able to include all the explanatory variables that influence renewable energy consumption thus resulting errors from omitted variables that are usually accounted for in the error term. It was our intention to include Trade as proxy for trading among SSA countries, Access to improved sanitation facilities as a proxy for social wellbeing and PM2.5 as a measure for pollution. This was not possible as preliminary model specification tests eliminated these variables. Finally, for chapter 2 the database WDI had data up to 2014 for most variables failing to capture trends in renewable energy consumption from the last 6 years that are critical for this analysis.

In chapter 4, 5 and 6 our expected sample size was 1,350 for national survey based on the UN 2005 sample size selection criteria. Due to time and available resources, we were only able to manage 1006 for Rwanda and 1020 for Kenya. Given that the stratified sampling technique was used that was random and ensured representation of both urban and rural components in random counties/provinces in both countries, it is safe to assume that our sample was representative of both countries. Case studies show that each country has unique factors that determine the best renewable energy mix. This underscores the importance of public input into policy making, further making the case for why acceptance, awareness, attitudes and preference studies in other SSA countries is necessary. This will enable quality information for developing a comprehensive regional policy to serve as a road map for future renewable energy portfolios.

Public opinion is dynamic and fluctuates with time, choice experiment models for preference analysis have their limitation as they capture snapshot of individual preferences. It is apparent that preferences for both market and non-market goods are subject to change in each population group as well as in individuals. These changes could be influenced by changes in knowledge, perceptions, paradigm shifts and socio-cultural norms. Therefore, in-order to make meaningful interpretation of trends in future renewable energy options. It is important to have study follow-ups that serve to capture these trends. Moreover, future studies need to focus on specific renewable energy technologies and the new attributes such local community interests and scale of projects that have played a significant role in determining the shape of future projects. Future studies can use information, especially from the Willingness to pay estimates, to further model scenarios for renewable energy for both country and extrapolate for SSA. The scenario analysis used in this study is simplistic, there is a need for more advance models e.g. Computable general equilibrium (CGE) that take advantage of economic inputs to work out a policy scenario for

robust outcomes. Finally, the bottom-up policy approach suggested in the study not only extends to other SSA countries but to also other developing countries, in public participation in environmental, health and other social studies. The results support public participation as a key component of prioritizing policy initiatives.



